MIT Technology Review

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America's Drone Dilemma
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Bringing Back Lost Eyesight
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Computing advances are making even many white-collar workers obsolete.

Are we headed toward chronic unemployment?

<!-- see p28 -->

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PORSCHE

From the Editor

While we await Immanuel Kant's perpetual peace, there will be wars; and if the president of the United States must sometimes defend the bad against the worse, perhaps it's as well that he should make war with unmanned aerial vehicles, or drones.

To a fastidious and cautious politician, drone strikes are appealing. They cause fewer civilian casualties than other forms of air war, because the munitions are small and accurate. Compared with any deployment of troops—even with what the military euphemistically calls "direct action" (the kind of special-forces operation that killed Osama bin Laden)—drone strikes have few costs and little risk.

These facts explain why drones have become "the favored technology for targeted assassinations in the global war on terror," according to Fred Kaplan in "The World as Free-Fire Zone" (see page 36). They are a peculiarly American weapon: today, while many countries use drones for surveillance, only the United States has the combination of intelligence-gathering and targeting technologies to kill a particular person or type of person anywhere, at any time.

The fierce distaste critics feel for this "arrogant sort of warfare," Kaplan writes, is the common, historical reaction to any new weapon that kills from a distance. People felt same way when the Royal Air Force bombed Germany's cities during the Second World War. But, he concedes, drones *are* different. One way they are different is they're so easy to use that commanders order strikes in parts of the world where the United States is not at war. The effect upon us is of course regrettable; monopolies, especially those of violence, are corrupting to those who enjoy them. But drone strikes may also possess negligible strategic value. There is a wearying futility to the whole business: when a number 3 leader of al-Qaeda is taken out by a drone, Kaplan says, there's always some number 4 leader of al-Qaeda ready to take his place.

The development of drones should remind us that technological advances are not the same as progress (a fact often forgotten, at least by technologists). Elsewhere in this issue, David Rotman explains how robots, automation, and software have increased the productivity of the United States at the same time that job growth has wilted (see "How Technology Is Destroying Jobs," page 28). Some economists believe that technological change has been "destroying jobs faster than it is creating them, contributing to … the growth of inequality." Rotman concludes that economists don't know if the decoupling of productivity from employment is permanent; but he says it's "hard to ignore … that technology is widening the income gap between the tech-savvy and everyone else."

Drones and automation push humans to the perimeter of activities where they were once the central actors. Both writers suggest that whether the advance of machines into war and work is a progressive matter depends less on the technologies themselves than on how we choose to react and adapt to our newfound capabilities. Kaplan deplores covert use of drones by the Central Intelligence Agency and wishes the flights to be part of the ordinary, legally restricted military operations conducted by the Department of Defense. One economist Rotman quotes, who believes the economy may have really changed, says that our ability to recover will depend on recognizing the problem and taking such steps as investing more in the training and education of workers.

Both insist that we must think how we wish to use new technologies, and not be used by them. But write to me at jason.pontin@technologyreview.com and tell me what you think.

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"The top and bottom are clearly getting farther apart."

How Technology Is Destroying Jobs, p28

WALTER SMITH

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Feedback

5 Most Discussed Stories

MIT Technology Review Volume 116, Number 3

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Reviews

Climate Change: The Moral Choices

The effects of global warming will persist for hundreds of years. What are our responsibilities and duties today to help safeguard the distant future? That is the question ethicists are now asking.

By David Roman

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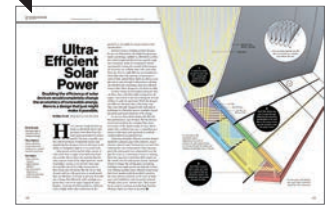
Ultra-Efficient Solar Power

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Climate Change: The Moral Choices

The only moral choice is this: Will we steal even more from the next generation using the false promise of "solutions right now," or will we demonstrate the wisdom to simply wait for the real emerging solutions to become both desirable and commodity priced? **—breister**

It's funny to see the comment area of every climate change article. There are more posts from people who deny it than from people who accept it. Where do all the deniers find the time to go around and post on everything? **—5862xwg**

Ultra-Efficient Solar Power

What solar needs most, in my opinion, is efficient, sustainable, and inexpensive energy storage; we can produce solar power well enough, but making it available whenever it's needed drives up the price. **—Tsuarok**

I think it's more accurate to say storage is a major issue, not the issue. If solar becomes cheap enough through a doubling of conversion efficiency, then everyone could afford it, at least to meet demand for half a dozen hours a day. So, yes, solar might never meet 24/7 demand, but then it doesn't need to. **—falstaff**

Deep Learning

I think we'll see a blurring between computer science and AI with biological science and our deeper understanding of brain structure, functioning, and consciousness. Very interesting times. **—Hotgirlpilot**

Machines help us think already. The ease of finding and organizing information—this is what makes us better thinkers now. I recall how in the gloomy days of old, one would have to spend days in dusty libraries to find some speck of data that today we can locate in seconds. As AI becomes widespread, these intellectual helpers will become self-driving cars: the sky's the limit. **—zdzisiekm**

Proceed with Caution toward the Self-Driving Car

I would rather see less driving automation and more active monitoring systems for vehicle parts: engines that are aware of the condition of wear and gunk; hoses and belts with embedded sensors to detect wear and damage; tires that know when they are worn or if they are out of alignment. I would also like to see more technologies built into the roads and highways. Automated traffic flow control. Digital speed limit signs that change with the changes of traffic, and direction signs that can suggest alternate routes. **—Brad1966**

The Enduring Technology of Coal

World coal consumption is at eight billion tons, and there's one trillion tons of coal on public lands in the United States, which represents 125 years of consumption. So where else do you think energy technology will be in 125 years? **—eric25001**

According to OPEC, coal will be the first source of primary energy in 2035. International Energy Outlook 2011, from the U.S. government, has coal in second place, but with an increase of 50 percent in 2035 compared to 2008. That's gonna happen, despite AGW alarmists. **—luisvb**

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Survivor: Earth

"The effects of global warming will persist for hundreds of years," writes David Rotman in his essay "Climate Change: The Moral Choices" (May/June 2013). "What are our responsibilities and duties today to help safeguard the distant future?" he asks. I felt attracted by the review at once, but I kept putting it off again and again because something bothered me about the title all the while. The books in the accompanying list of what's being reviewed are by

> **"The time to think seriously about the future has long passed. What humanity is actually facing at this juncture is mere survival."**

Stephen Gardiner, John Broome, Clive Hamilton. All three are professors of philosophy with an accent on ethics. As I surmised from the beginning, though, they have little to offer by way of practical advice.

Predictably, the review ends up pretty much nowhere as well. In the last sentence, Rotman quotes Gardiner: "The time to think seriously about the future of humanity is upon us." And it was this sentence that finally reminded me of Keith Farnish—whose book precedes by a couple of years the first book reviewed. He argues, to my satisfaction, that the time to think seriously about the future has long passed. In other words, humanity is not facing ethical tragedies and moral storms any longer. What it is actually facing at this juncture is mere survival. Put differently, earth masters we surely are not. Rather, we are much closer to being earth slaves.

– Ranko Bon
Motovun, Croatia

Look on the Bright Side

David Rotman's review on climate change made me think: We shouldn't underestimate our willingness to sacrifice now to benefit our children and their children. Look no further than the concluding clause of the Preamble to the U.S. Constitution—"to secure the blessings of liberty to ourselves and our posterity ..." If the scientific community can speak as one (and that's the real problem right now) as to what will happen to our children and their children if we don't make certain sacrifices now, we will do it. In my opinion, in an emotionally healthy adult there is no greater motivation than the survival of one's progeny. **– Civilian2013**

Facebook Had It Easy

Regarding your Business Report story "How Facebook Slew the Mobile Monster" (May/June 2013): I think Facebook is given way too much credit for what they've done in mobile advertising. When you have a social network of a billion and a bunch of information about those users, it isn't that hard to monetize the platform. **– AndyTill**

There Will Be Blood

Your story "Google Wants to Install a Computer on Your Face" (May/June 2013) made me think of a company I once worked for that wanted to put a video camera into sunglasses to give users a view on the world. What they didn't count on was the revulsion it got. People in shopping centers and such got upset at the thought they were being filmed without their permission.

Privacy will be the biggest issue Google Glass has to overcome. I sincerely doubt it will. Might I suggest that wearers be given free health insurance to counter the bloody noses they may have to endure on a daily basis?

– DeveloperChris

Views

Arthur Caplan

Helen Greiner

Paul Anastas

NEUROSCIENCE

Deleting Memories

Techniques that can soften or erase memories raise many ethical questions, says Arthur Caplan.

It should go without saying that the ability to selectively erase memories would be a very useful one to have. A person suffering night after night from post-traumatic stress disorder that is resistant to drugs or cognitive therapy would be able to resume his or her career. A young child who cannot forget the horror of watching a parent die in an automobile accident would finally see relief.

But before we get overly enthusiastic about the prospect of drugs and cognitive tricks that might erase unwanted memories or block their formation (see "Repairing Bad Memories," page 48), a number of thorny ethical questions need to be examined.

While getting rid of horrible memories sounds great, the research needed to fine-tune this process may require subjects to risk the loss or alteration of other, wanted memories. How much risk should these research subjects be allowed to take? The answer must take into account the dangers not only to their health but also to their sense of personal identity and selfhood.

Presuming that we can learn how to remove or weaken particular memories, how certain can we be that their loss will be our gain? The fact that too many people are tortured by what they cannot forget does not mean everything unpleasant in the realm of memory is bad. Not all our worldly experience is pleasurable, but all of it can still be hugely meaningful and constructive for us to remember.

We all learn from our mistakes, and adversity is a crucial part of what makes us who we are. What makes you modest, humble, introspective, deliberative, empathetic, and prudent—in short, virtuous—may be driven by memories of experiences that are unpleasant, disturbing, and shameful. I don't like remembering my failures and errors, but as I struggle to be a better person, I most certainly would not want to have them vacuumed out of my neural net or yours.

Moreover, some of our collective bad memories—of holocausts, mass murders, pandemics, natural catastrophes, and wars—are precisely the ones we may long to obliterate. The advice that we, humanity, must "never forget" such events is sound, and we must weigh it against the desire to erase the pain of remembering.

Memory erasure has the potential to be a powerful and valuable tool. But it is one requiring a good deal of ethical reflection and oversight.

Arthur Caplan is a professor and founding head of the Division of Bioethics at New York University's Langone Medical Center.

DRONES

Flying Robots

Compact unmanned aerial vehicles will perform many valuable jobs if aviation regulations allow them to operate commercially, says Helen Greiner.

I don't use the word "drone," which originally referred to remotely piloted planes used for anti-aircraft target practice and is now closely associated with long-range surveillance and strike vehicles operated by the military (see "The World as Free-Fire Zone," page 36). But I do envision wider use of aircraft with sensors, perception, and intelligence. I call them "flying robots."

Unmanned aerial vehicles, as they can also be termed, are already being used for

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Views

incredible things. Some Japanese farmers get help managing their rice paddies from UAVs that monitor crops and spray pesticides, while UAVs with cameras are used to track wildlife poachers in Africa. When I went kite-boarding in Utah recently, I saw hobbyists using UAVs to capture their experiences from a unique angle.

Unfortunately, though, we are still missing out on much of the potential of flying robots. All the current applications are governmental, hobby-related, or overseas, because the Federal Aviation Authority completely restricts the commercial use of UAVs in U.S. airspace. Happily, this is expected to change in 2015. I believe this change will cause an explosion in commercial applications of flying robots.

Just using flying robots as eyes in the sky will be incredibly valuable. Bridges, dams, and other civil infrastructure require periodic inspections, a mostly visual task that a small flying robot can perform much more quickly and cost-effectively than a person dangling on a rope. At a time when an estimated 17,000 U.S. bridges are behind in their scheduled inspections, UAVs could cut the dangerous backlog. Police will also benefit from using flying robots with cameras, allowing them to assess dangerous situations before intervening. Ground-based robots used in this way by U.S. military overseas have already saved the lives of service personnel and civilians.

These first applications will create a virtuous cycle of profits and investment that can support more advanced ideas. For example, flying robots could be used to transport documents and small parts efficiently within urban areas. In the longer term, these robots will be able to act more intelligently. They could swarm a litter-covered area and leave it pristine, or fly toward the sound of gunshots and throw themselves into the line of fire.

They could also have personal uses. Imagine a flying robot that meets you at the halfway point of a run or hike with cool water. Like a family dog, it might even play catch, watch the house, and show excitement when you return home from work.

Helen Greiner is chief executive officer and cofounder of Cyphy Works, a company developing flying robots for commercial use. Previously, she cofounded iRobot and served as its president and chairman.

CHEMISTRY

Greener Plastics

Plastics have become synonymous with waste, but they can be made sustainably, says Paul Anastas.

There can be little doubt that plastic materials have dramatically improved everything from clothing to travel to communications to building. Some of the damage they have caused, however, is equally dramatic.

The most well-documented concerns about traditional plastics relate to their persistence in the environment. Plastic bags and water bottles fill up landfills, and plastic fragments gather in high concentrations in a large area of ocean known as the Great Pacific Garbage Patch. Less well known is that for every bit of solid waste floating in the ocean, as much as an equal amount of soluble plastic has dissolved in the water, where it can harm marine life.

We can create plastics without polluting.

Paul Anastas

Avoiding these problems doesn't mean we must do without plastics. It is possible to create plastics that end their lives without polluting or poisoning (see "Plastic from Grass," page 84).

Plastics created using the principles of "green chemistry" are designed to reduce or eliminate the use and generation of hazardous substances throughout their life cycle. This means nontoxic, renewable feedstocks, a manufacturing process that yields little or no waste, and a final plastic that, when discarded, degrades into harmless products on a human rather than a geologic time scale.

Green plastics can be made synthetically, but most are made from biomass feedstock. In recent years, the large-scale manufacturing of polylactic acid (PLA, made from starches) and polyhydroxyalkanoates (PHA, fermented from sugars or fat) has show that there may be significant market niches for green bioplastics.

PLA has been used in applications ranging from food packaging to automotive components to clothing. While its current market share is small, there are significant reasons to be optimistic that it will take on a bigger role and that green plastics in general will become more competitive.

Growth in the use of biofuels, though modest, increases the incentive to develop applications for nonfuel materials produced in biorefineries. Progress is being made toward addressing the performance limitations of bioplastics like PLA using nontoxic additives, much as plasticizers can be used to soften brittle PVC and turn it into a rubber duck toy.

Most important, research is showing that formerly recalcitrant feedstocks such as grasses, agricultural wastes, and wood are promising bases for new materials. These plastics may have not only an environmentally friendly life cycle but enhanced performance, functions, and capabilities.

Paul Anastas, director of Yale University's Center for Green Chemistry and Green Engineering, previously served as assistant administrator for research and development at the Environmental Protection Agency.

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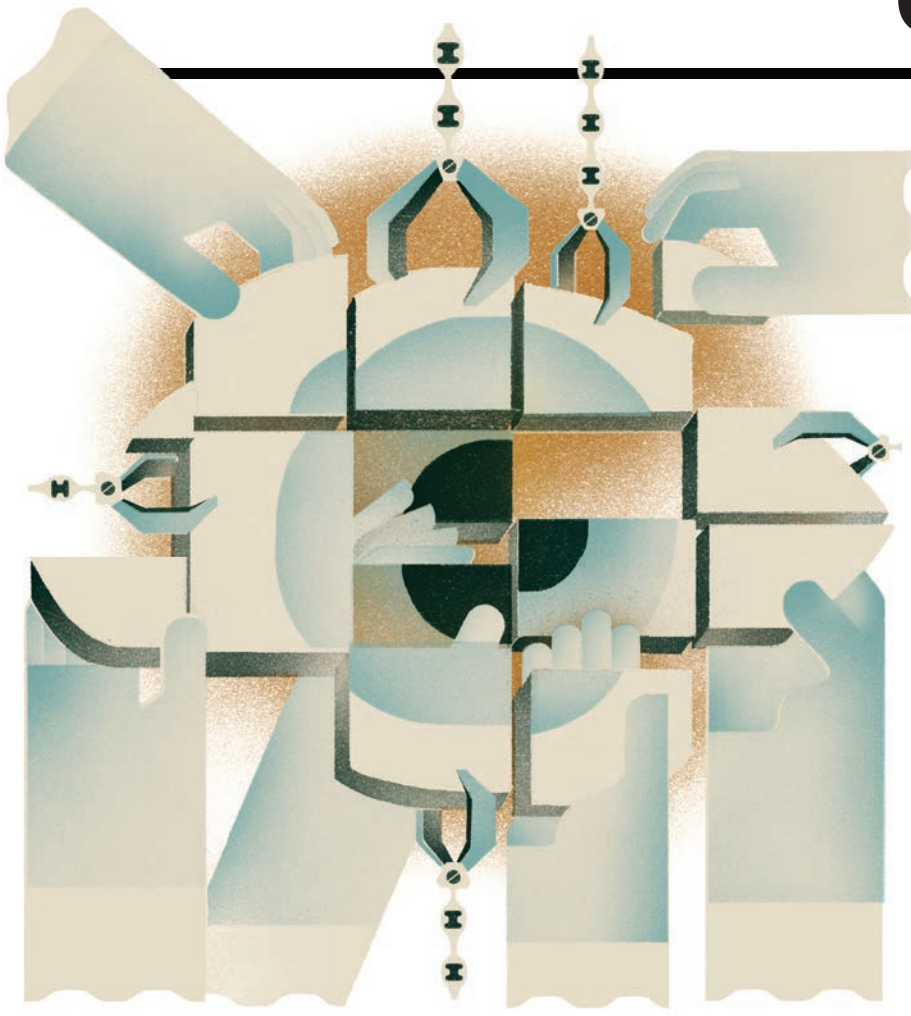


SERGIO MEMBRILLAS

Artificial Retinas Are Coming into View

Bionic vision gives the blind a sense of what's in front of them.

By Susan Young

Elias Konstantopoulos gets spotty glimpses of the world each day for about four hours, or for however long he turns on his Argus II retina prosthesis. The 74-year-old man lost his sight from a progressive retinal disease over 30 years ago, but he is able to perceive some things with the bionic vision system.

"I can see if you are in front of me, and if you try to go away," he says. "Or if I look at a big tree with the system on I can maybe see some darkness. And if it's bright outside and I move my head to the left or right I can see different shadows that tell me there is something there. There's no way to tell what it is."

A camera mounted on a pair of spectacles captures image data for Konstantopoulos; that data is then processed by a mini-computer carried on a strap and sent to an array of 60 neuron-stimulating electrodes that was implanted on one of his retinas in 2009.

Nearly 70 people around the world have undergone the three-hour surgery for the retinal implant, which was developed by California's Second Sight and approved for use in Europe in 2011 and in the U.S. this year. It is the first vision-restoring implant sold to patients.

Currently, the system (which costs 73,000 euros in Europe; the U.S. price is not disclosed) is approved only for patients with retinitis pigmentosa, a degenerative eye condition that strikes around one in 5,000 people worldwide. But it's possible the Argus II and other artificial retinas in development could work for people with age-related macular degeneration, which affects one in 2,000 people in developed countries. In that condition, the photoreceptor cells of the eye (commonly called rods and cones) are lost, but the rest of the neuronal pathway that communicates visual information to the brain is often still viable. Artificial retinas depend on this remaining circuitry, so they cannot work for all forms of blindness.

"Retina prostheses are at the stage cochlear implants were 30 years ago."

Many groups are working on ways to replace lost photoreceptors. Most use a camera that communicates to an implanted chip, but these systems vary in the number of electrodes in the chip and how deep the chip is placed inside the retina. Others eschew the camera for light-sensitive diodes in the chip. A German company called Retina Implant, for example, recently completed human tests

Upfront

QUOTED

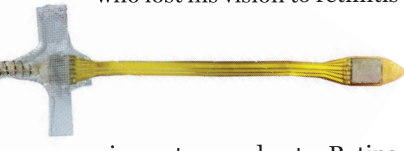
"When we look back on this era, we'll be amazed that the Internet was ever trapped behind glass."

– Matt Webb, CEO of the London-based technology consultancy Berg, talking about the potential for objects to be online in the "Internet of things."

of an implant that does not depend on a camera but instead directly harvests light and transmits that data to remaining neurons. A array of 1,500 photodiodes replaces the eye's photoreceptors.

At their best, today's artificial retinas produce only sketchy images. Patients see bursts of light called phosphenes and "not truly naturalist vision," says Raymond Iezzi, a clinician-scientist who performs retinal surgeries at Mayo Clinic in Rochester, Minnesota.

Some people with artificial retinas can read large letters, see slow-moving cars, or identify tableware. Tim Reddish, 55, who lost his vision to retinitis pigmentosa and got a Retina Implant device in November, says he can read a high-contrast clock indoors. Outside, he says, he can detect the lines of buildings with glass doors and the headlights of slow-moving cars at night.



This chip developed by Retina Implant has 1,500 photodiodes that stand in for the eye's photoreceptors.

But other patients experience no benefit. The variation can be ascribed in some cases to the exact placement of the neuron-stimulating array in the tissue-paper-thin retina as well as the state of the remaining neurons and pathways in each individual's eye. How well people can retrain their brain to use the device is also important. "Patients will scan their environment and use their memory to reconstruct what they are seeing," Iezzi says.

Second Sight says its Argus II provides 20/1,260 vision (which indicates that a person can see an object from 20 feet away that a normal-sighted person can see from 1,260 feet away). Retina Implant says the best visual acuity gained with its device is 20/1,000. For comparison, normal vision is 20/20 and the threshold of legal blindness in the U.S. is 20/200.

"Retina prostheses are at the stage cochlear implants were 30 years ago," says Anthony Burkitt, director of Bionic Vision Australia, a consortium of retinal-implant researchers. "That technology went from being an aid for lip reading to the point now where children with a cochlear implant can go through normal school and even use mobile phones."

One way to improve artificial retinas is to add more of the electrodes that create the pixels in the eye. Second Sight, for example, is planning on moving from 60 to 240 electrodes in a future model. But thousands of pixels will probably be required for facial recognition and other detailed visual tasks, and many artificial-retina technologies will have trouble achieving that because they have to be powered through surgically implanted wires, says Daniel Palanker, a biophysicist at Stanford. To avoid this limitation, Palanker and colleagues are developing a wireless system in which a photovoltaic chip with flexible arrays of small pixels is implanted in the eye and receives image data captured by a video camera. The team has tested the system in blind rats and is working with a company to test it in patients.

Even thousands of pixels are far from the one million photoreceptors in a normal eye—which also does more levels of image processing than artificial retinas are likely to re-create. "I think it's going to be a long time to develop ways to get better vision, and I don't think it will ever be entirely natural," says Shawn Kelly, an electrical engineer at Carnegie Mellon University.

Nonetheless, patients like Konstantopoulos are encouraged. "Even that shadow I can see in front of me, whether it's a person or anything else, is something from nothing," he says.

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A plastic screen protector turns an ordinary iPhone 5 into one with a 3-D display—no glasses required. The plastic has half a million tiny lenses precisely patterned on its surface that send separate images to the left and right eye to create the illusion of depth. It's an update on lenticular lens technology, which was invented over a century ago and is used to make postcards that move as the viewer's perspective shifts. In the plastic screen cover, each lens is small enough to sit above an individual pixel in a high-resolution LCD display. It's significantly cheaper than other methods of making glasses-free 3-D possible. Now the Singaporean company that developed the technology plans to help game makers and other developers create 3-D content that would make use of it.

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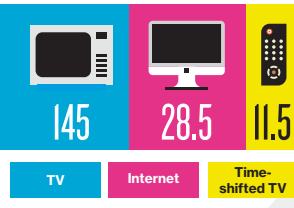
Upfront

TV STAYS IN THE PICTURE

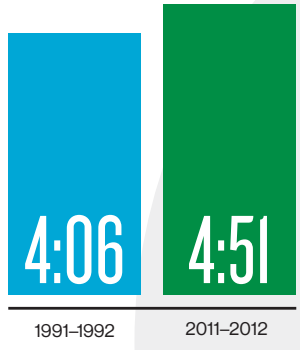
Although we have more ways to entertain ourselves than ever, it's proving hard to unseat television as the most popular mass medium. Americans watch nearly five hours of traditional broadcast and cable TV every day—and that doesn't even count the time they spend on Internet video sites.

Average monthly media viewing, in hours



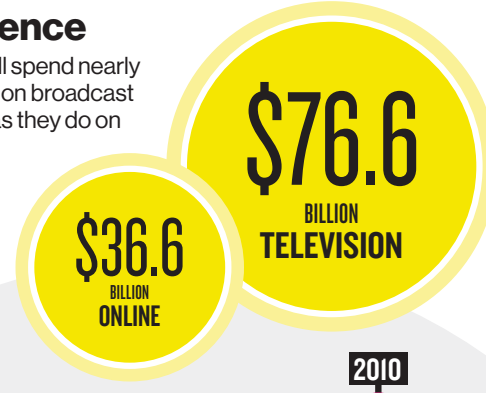
Average daily TV viewing, in hours

The advent of the Web didn't cut into TV time.



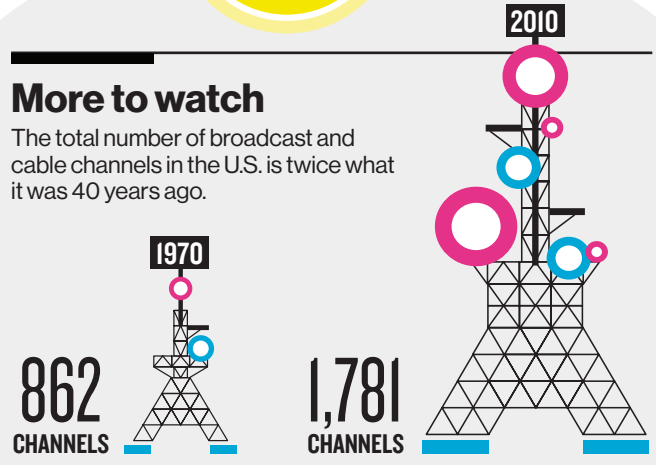
The power of the audience

Advertisers still spend nearly twice as much on broadcast and cable TV as they do on the Web.



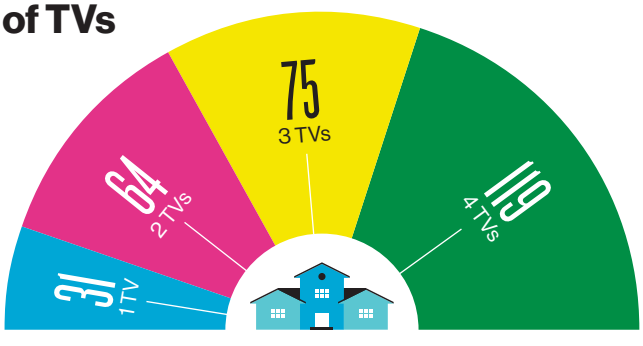
More to watch

The total number of broadcast and cable channels in the U.S. is twice what it was 40 years ago.



Households, in millions, by number of TVs

Most households can watch more than one show at a time.



Percentage of households with multiple sets

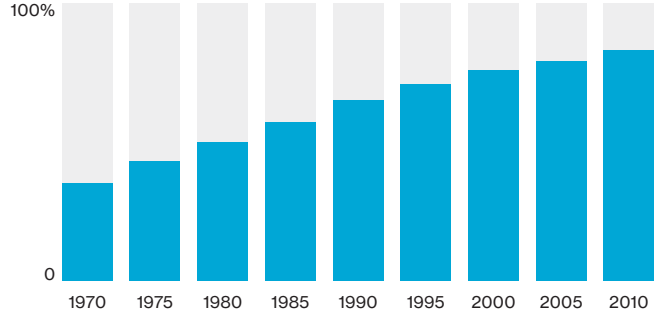
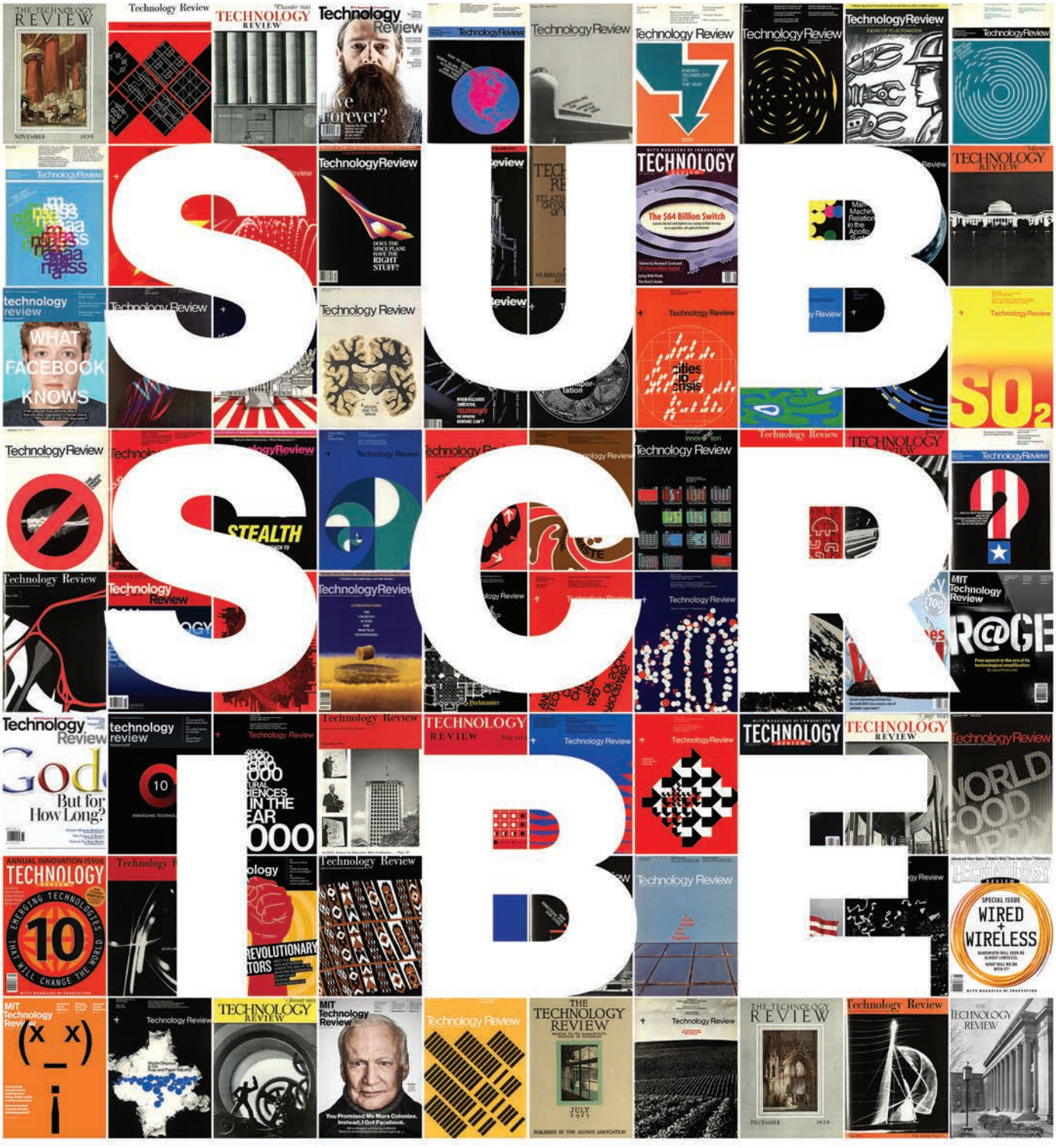


ILLUSTRATION BY LAURA CATTANEO; DATA FROM U.S. CENSUS (TV STATIONS), INTERACTIVE AD BUREAU (ONLINE AD MARKET), NIELSEN (VIEWING TIME, HOUSEHOLD TVS, TV AD MARKET)



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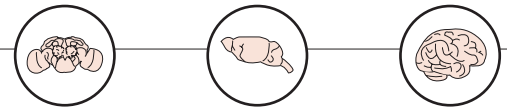
Upfront

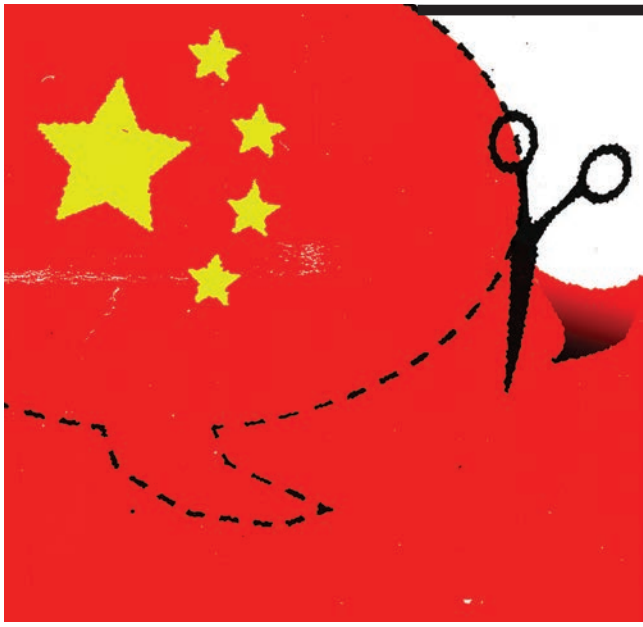
The Early Days of Brain Mapping
Scientists will need several years before they can track even tens of thousands of neurons at once.



FLY BRAIN
100,000 neurons

MOUSE BRAIN
75 million neurons

HUMAN BRAIN
85 billion neurons



Reading the Tea Leaves of Censorship

Examining which posts get removed from social networks can help reveal China's plans.

By Tom Simonite

In February of 2012, the fast-rising Chinese politician Bo Xilai suddenly demoted his top lieutenant, who then accused his boss of murder. It triggered Bo's downfall and a major scandal.

Although the story came out of the blue, software developed by Gary King had detected signs days earlier that a major political event was about to occur. King, a researcher at Harvard, uses the software to monitor government censorship on multiple Chinese social-media sites. Five days before Bo demoted his advisor, the software registered the start of a steady climb in the proportion of posts blocked by censors.

King says he has noticed similar patterns several times in advance of major political events in China. For example, dissidents' names suddenly begin to be censored days before they are arrested. "We have examples where it's perfectly clear what the Chinese government is about to do," he says. "It conveys way more about the Chinese government's intents and actions than anything before."

A jump in the overall censorship rate, like the one that foreshadowed Bo's fall, also presaged the arrest of artist Ai Weiwei in 2011. The rate declined in the days before the Chinese government announced a surprise peace agreement with Vietnam in June 2011, defusing a dispute over oil rights in the South China Sea. King suspects those patterns show that censors are being used as a tool to dampen or otherwise shape the public response to forthcoming news.

China's social-media censorship is less well understood than the system known as the Great Firewall, which blocks access to foreign sites, including Facebook and Wikipedia, from inside the country. But studies like King's are beginning to reveal that the country's censorship occurs through a sophisticated, efficient operation that can be carefully deployed to steer the nation's online conversation.

The most popular social-media services in China are microblog networks, or "weibos," which are roughly equivalent to Twitter and are used by about 270 million people, according to government figures. All weibos must establish an internal censorship team, which takes directions from the government on filtering sensitive posts. Sina Weibo and Tencent Weibo, which between them claim the majority of active users, are said to have censorship teams as large as 1,000 people.

Those teams can act fast, as a study of 2.38 million posts on Sina Weibo (12 percent were censored) showed last year. "It's minutes or hours, not days," says Jed Crandall, an assistant professor at the University of New Mexico, who took part in research with colleagues from Rice University and Bowdoin College. "There must be some automation tools that would help them, or they wouldn't be able to do the rate that we observed."

Crandall has also uncovered evidence of how Chinese censorship is used to steer the direction of public conversation rather than just being used to block out sensitive topics completely. His software detected a successful effort by censors to dampen the online outcry after a major train crash in 2011. The censors relented once public chatter had shifted onto more favorable terms.

This is not to say that China has the social Web fully under control. Dissent still exists on weibos, where users invent code words to talk about censored topics. However, the findings of King, Crandall, and others make it clear that studying censorship could be very useful to anyone trying to figure out the Chinese government's priorities, concerns, and plans.

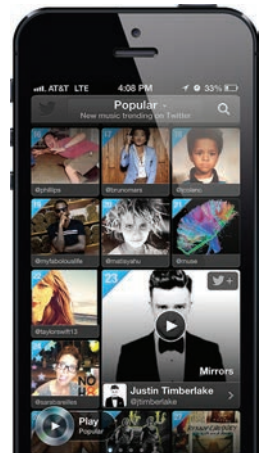
DANIEL ZENDER

With a Little Help from My Friends

New social-media apps make it easier to discover and share music. *MIT Technology Review* IT editor Rachel Metz sounded out the high and low notes of a few of them.

Share your friends' songs by "repicking" them.

The iPhone app is beautiful, with artists in a scrollable grid.



Adjust the influence each friend has on the music suggested for you.

Piki

PRICE: free

AVAILABILITY: iPhone, online. Android soon.

Piki lets you hear what your friends are listening to and pick songs you think they should hear, too. You can pick that music by letting the app's microphone listen to what's playing around you, by searching the library on your iPhone, or by searching for songs or artists. The tunes you pick will be shared with your friends on Piki, as will any friends' songs you "repick."

You can control how much you want individual friends to influence your music stream by raising or lowering each person's "play frequency." And you can tell Piki to play songs suggested by people who like certain bands or musical genres. Though I don't know many people using Piki, I added "friends" on the service by spotting users whose tastes seemed similar to mine. I was pleasantly surprised by the results.

Twitter #music

PRICE: free for samples

AVAILABILITY: iPhone, online

Twitter #music sounds like a great idea: it mines activity on the social network to determine popular songs, to recommend artists it thinks you'll like, and to show you the musicians your friends are following.

The iPhone app is beautiful, with artists shown as small squares within a scrollable grid. The app's music player includes a sleek take on the visual of a spinning record, with the artist's album art rotating above a volume slider that pulses to the beat.

However, Twitter #music is more about finding new artists than actually listening to new songs. You can hear only one song from each listed artist, and you need a $10-per-month premium account on Spotify or Rdio to do even that. Otherwise, you'll just hear a sample from Apple's iTunes store, and you'll be punted over to iTunes if you want to buy the song.

EQuala

PRICE: free

AVAILABILITY: iPhone, Android

EQuala is my favorite. From the songs you listen to and share through the service, it gleans your "music DNA"—a readout of your musical taste. It suggests songs by comparing your taste to your friends'; it figures out their interests from the songs they share on Facebook through services like Spotify, Pandora, and Rdio. The app's best feature is its Friends Equalizer, which lets you adjust the influence each friend has on the music suggested for you.

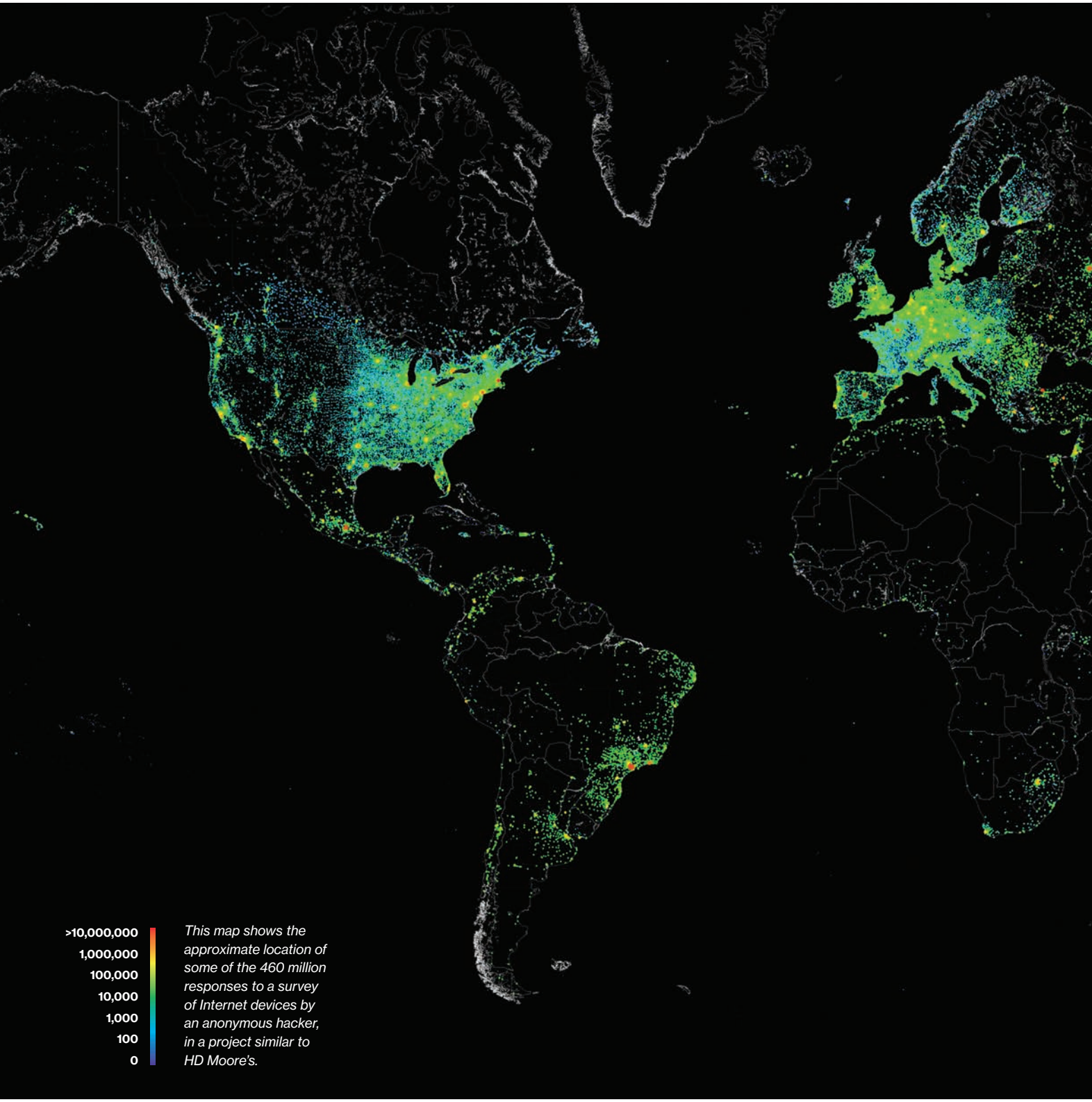
Once you hit "play," EQuala streams tunes radio-style, stopping occasionally for an ad. Like many Internet radio services, it has a song-skipping limit (you can skip up to six songs per hour).

It's not the best-looking app, but it figured out what I like. It reliably turned me on to new music and reminded me of artists I had forgotten about.

COURTESY OF PIKI; COURTESY OF TWITTER; COURTESY OF EQUALA

Upfront

86 percent: Increase in average Internet connection speeds in Kansas after Google announced plans to bring ultrafast fiber-optic service to a small slice of the state.



This map shows the approximate location of some of the 460 million responses to a survey of Internet devices by an anonymous hacker, in a project similar to HD Moore's.

MIT TECHNOLOGY REVIEW
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What You Can Find When You Ping the Whole Internet

A home science experiment reveals huge security problems.

By Tom Simonite

CARNA BOTNET

You probably haven't heard of HD Moore, but until this spring every Internet device in the world, perhaps including some in your own home, was contacted roughly three times a day by a stack of computers that was overheating his spare room. For Moore, who leads research at the computer security company Rapid7, this was a hobby, but the results weren't all fun. He revealed serious security problems in business computers used to control everything from traffic lights to power infrastructure.

Moore's census involved regularly sending simple, automated messages to each of the 3.7 billion IP addresses assigned to devices connected to the Internet (Google, in contrast, collects only information offered publicly by websites). The replies he got from 310 million IPs indicated that they came from devices vulnerable to well-known flaws or configured in a way that could let anyone take control of them. A particularly troubling segment of those vulnerable devices appear to be sensitive industrial systems. Many could be accessed using default passwords; 13,000 offered access through a command prompt without a password at all.

Those vulnerable accounts offer attackers significant opportunities, says Moore. They might be able to reboot company servers and IT systems, access medical device logs and customer data, and even gain access to control systems used in factories or the power infrastructure. Moore's findings were bolstered by results published in March by an anonymous hacker who did a global scan using 420,000 compromised pieces of network hardware.

Billy Rios, a security researcher who works on industrial control systems at the security startup Cylance, says Moore's project valuably quantified the scale of a problem that is well-known to experts like himself but underappreciated by companies at risk.

For his part, Moore believes the security industry is mistakenly focusing mostly on the computers used by company employees. "We've got some much bigger issues," he says. "There [are] some fundamental problems with how we use the Internet today."

Upfront

$800 million: The cost of the first comprehensive large-scale "smart grid," which Florida Power & Light completed this spring.

An aerial view of Shell Scotford, an oil sands refinery near Edmonton, Alberta. A government-funded project will annually capture and store more than one million tons of carbon dioxide from Scotford beginning in 2015.

Can Carbon Capture Clean Up Canada's Oil Sands?

Alberta will serve as a test bed for a crucial technology.

By Mike Orcutt

Canada is about to make the world's biggest bet on carbon capture and storage (CCS), a technology that is unproven at the scale needed to significantly decrease greenhouse gas emissions.

If things go as planned with CCS at Alberta's massive oil sands, Canada could help the technology finally begin to scale up. There has been no other significant test of the type of large network of pipelines, capture facilities, and storage reservoirs that will be required for CCS to play a significant role in reducing emissions.

Deployment of CCS has been held back by high costs, uncertainty about risk, and the lack of incentives for large emitters to invest in the technology. The International Energy Agency has said that the construction of large CCS facilities is far behind schedule if the technology is to have much impact on climate change.

The government of Alberta has committed over $1.2 billion to two projects meant to capture, transport, and store carbon dioxide from so-called "upgraders," the facilities that convert bitumen extracted from the oil sands into crude oil. One project will be at a large processing facility run by Shell; its carbon dioxide will be injected into a deep saline aquifer for permanent storage. Another project will connect processing sites to operations that will use the captured carbon dioxide to recover hard-to-reach oil, a process called enhanced oil recovery. The projects also have support from Canada's national government.

Oil from the oil sands generates up to 4.5 times more carbon dioxide than oil from conventional sources. The industry is responsible for between 40 and 50 million metric tons of carbon dioxide every year, or around 7 percent of Canada's total emissions. Mike Fernandez, executive director of sustainable energy for Alberta's energy ministry, says the goal is to be storing 2.76 million tons by late 2015, and 139 million by 2050.

But for CCS to really take off, it will need much stronger incentives. Alberta now decrees that high emitters unable to reduce their emissions by 12 percent must pay $15 per ton of carbon dioxide emitted. But that price is too low to amount to much of an incentive for emitters to pay for CCS themselves, says Fernandez. He says the provincial government is considering an increase in the carbon price.

TO MARKET

Material Change

i3

COMPANY: BMW

PRICE: $40,000 to $50,000

AVAILABILITY: Autumn

Light, stiff, and strong, carbon-fiber-reinforced plastic has long been used in racing cars. Now, BMW will produce the body of its i3 electric car with the material, making it possible for the small coupe to have a range of 100 miles even with a small and cheap battery pack. Carbon fiber is 30 percent lighter than aluminum and half the weight of steel, but its expense has until now kept it out of high-production cars. BMW spent years working with a German company, SGL Group, to economically manufacture the material and integrate it into mass production lines.

COURTESY OF SHELL; COURTESY OF BMW

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Q+A

Thad Starner

Few gadgets have generated as much excitement and hostility as Google Glass, a voice-activated computer-monitor combo worn on eyeglass frames. Now being tested by early adopters, Glass is an ambitious attempt to advance "wearable computing." It's also a milestone for Thad Starner, a Georgia Tech professor who has been building and wearing head-mounted computers since 1993. A decade ago, he showed Google founders Larry Page and Sergey Brin a clunky version of such a device; in 2010 they hired Starner to be a technical lead for Project Glass. Starner told IT editor Rachel Metz why he thinks people will soon crave the ultrafast communication that the device makes possible.

Does the arrival of Glass make you feel that everyone else can finally catch up to your way of seeing the world?
Yes. Real smartphones didn't really come out until the mid-2000s. For [wearable-computing advocates], the smartphone was kind of a letdown, because it's something that takes your attention off the real world. It's something that's very hard to use effectively while walking down the street. It's so fast for me to get information in and out [of the wearable computer] that it's much less socially obtrusive.

How is Glass less obtrusive than a smartphone? You're wearing something on your face.
For me to go back and look for a message I sent you last takes me a few seconds. It's something I can do all the time. It's not something you can do all the time with a smartphone.

There's already been a backlash, in large part because people can use Glass to make hands-free videos of their surroundings. Users are being called "Glassholes." Does this surprise you?
I've been seen with interactive systems since 1993. There's nothing I've heard [about Glass] that I haven't heard before. And most of the time people, when they talk about these issues—they haven't actually used one. They've never actually seen somebody use one. Can bystanders notice you're using it? As a matter of fact, Glass does a very good job of that. You can actually see what the person is doing. You can actually see there's a camera on. Glass makes a horrible, horrible spy device.

Still, a lot of people think it's ridiculous.
So were most new devices when they were introduced. So were cell phones, right? So were eyeglasses. So were cars.

That's lofty, isn't it, to compare Glass to things like the automobile?
I believe if we reduce the time between intention and action, it causes a major change in what you can do, period. When you actually get it down to two seconds, it's a different way of thinking, and that's powerful. And so I believe, and this is what a lot of people believe in academia right now, that these on-body devices are really the next revolution in computing.

If I want a wearable computer, couldn't I just get a wristwatch device like Pebble?
They don't quite have the functionality. How do you take the picture of your baby's first steps with a wristwatch?

You can take out your phone. Isn't it okay to get a photo of the third step?
It takes 20 seconds to get that picture. Then it's already happened, it's already passed. The same thing with a wristwatch. You don't really have a good way of taking a good picture with a wristwatch from a first-person perspective. I think the heads-up display is a better interface for most things you want to do.

How will Glass change the way we interact with each other?
Well, now you'll actually be able to capture your baby's first steps.

But in terms of having a conversation with your wife or your kids, you don't think people will find it distracting?
If I walk by my students at Georgia Tech and you ask them, "Was he wearing it or not?" they can't tell you. It's just so a part of me, they don't even notice it anymore.

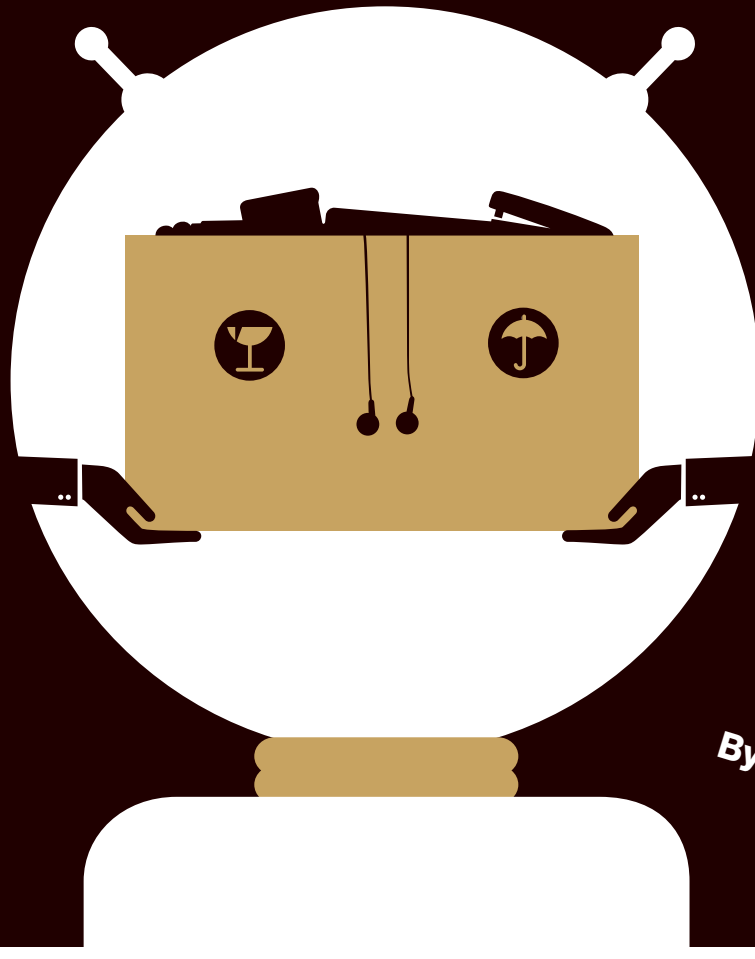
What other applications would you like to see Glass have in the future?
I'll tell you one thing I found compelling early on—this is something from 1993, called the Remembrance Agent. Imagine that as you're, say, writing up this article, as you're typing along, it pulls up articles from your past, or notes from your past, that might be relevant to what you're currently typing. Having something that's continually watching what you're typing that will help pull up your past memories is really surprisingly powerful.

There's a lot of ways to improve it. A lot of it is going to be in how people use it, how people integrate it into their lifestyles. People always talk about the killer app, but this is more a killer lifestyle. It's a killer existence.

Portrait by Audra Melton

MIT TECHNOLOGY REVIEW
VOL. 116 | NO. 4

How Technology Is Destroying Jobs



By David Rotman

Illustration by Noma Bar

Automation and advanced digital technologies are eliminating the need for people in a growing number of jobs. We've survived severe technological changes before, but this time it might be different: are we facing a future of dismal job opportunities, stagnant income, and worsening inequality?

iven his calm and reasoned academic demeanor, it is easy to miss just how provocative Erik Brynjolfsson's contention really is. Brynjolfsson, a professor at the MIT Sloan School of Management, and his collaborator and coauthor Andrew McAfee have been arguing for the last year and a half that impressive advances in computer technology—from improved industrial robotics to automated translation services—are largely behind the sluggish employment growth of the last 10 to 15 years. Even more ominous for workers, the MIT academics foresee dismal prospects for many types of jobs as these powerful new technologies are increasingly adopted not only in manufacturing, clerical, and retail work but in professions such as law, financial services, education, and medicine.

That robots, automation, and software can replace people might seem obvious to anyone who's worked in automotive manufacturing or as a travel agent. But Brynjolfsson and McAfee's claim is more troubling and controversial. They believe that rapid technological change has been destroying jobs faster than it is creating them, contributing to the stagnation of median income and the growth of inequality in the United States. And, they suspect, something similar is happening in other technologically advanced countries.

Perhaps the most damning piece of evidence, according to Brynjolfsson, is a chart that only an economist could love. In economics, productivity—the amount of economic value created for a given unit of input, such as an hour of labor—is a crucial indicator of growth and wealth creation. It is a measure of progress. On the chart Brynjolfsson likes to show, separate lines represent productivity and total employment in the United States. For years after World War II, the two lines closely tracked each other, with increases in jobs corresponding to increases in productivity. The pattern is clear: as businesses generated more value from their workers, the country as a whole became richer, which fueled more economic activity and created even more jobs. Then, beginning in 2000, the lines diverge; productivity continues to rise robustly, but employment suddenly wilts. By 2011, a significant gap appears between the two lines, showing economic growth with no parallel increase in job creation. Brynjolfsson and McAfee call it the "great decoupling." And Brynjolfsson says he is confident that technology is behind both the healthy growth in productivity and the weak growth in jobs.

It's a startling assertion because it threatens the faith that many economists place in technological progress. Brynjolfsson and McAfee still believe that technology boosts productivity and makes societies wealthier, but they think that it can also have a dark side: technological progress is eliminating the need for many types of jobs and leaving the typical worker worse off than before. Brynjolfsson can point to a second chart indicating that median income is failing to rise even as the gross domestic product soars. "It's the great paradox of our era," he says. "Productivity is at record levels, innovation has never been faster, and yet at the same time, we have a falling median income and we have fewer jobs. People are falling behind because technology is advancing so fast and our skills and organizations aren't keeping up."

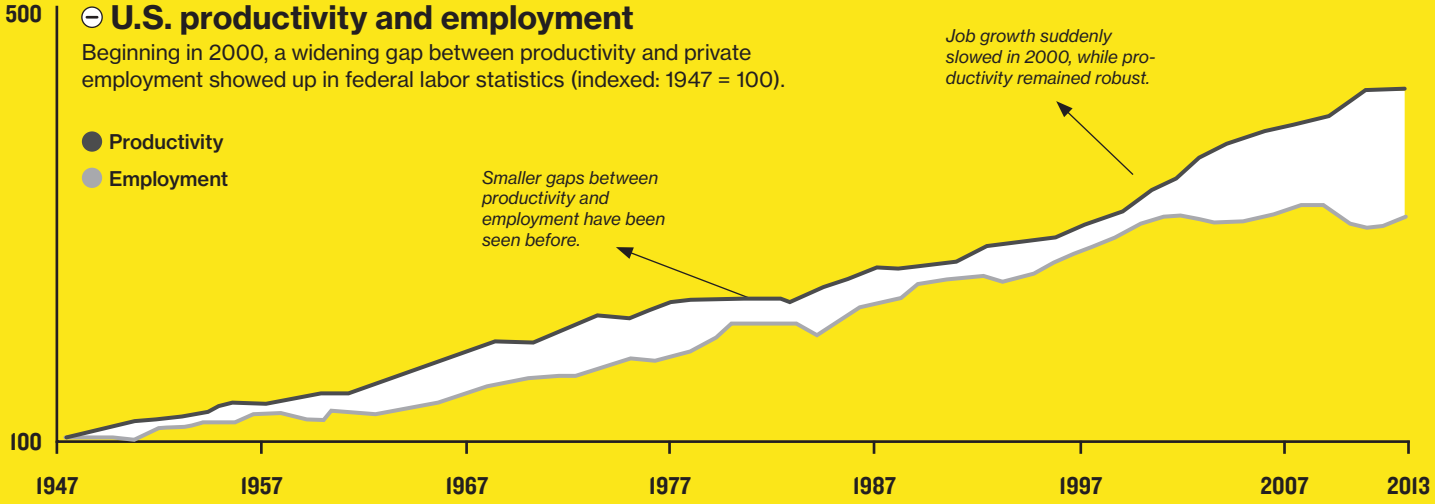
Brynjolfsson and McAfee are not Luddites. Indeed, they are sometimes accused of being too optimistic about the extent and speed of recent digital advances. Brynjolfsson says they began writing *Race Against the Machine*, the 2011 book in which they laid out much of their argument, because they wanted to explain the economic benefits of these new technologies (Brynjolfsson spent much of the 1990s sniffing out evidence that information technology was boosting rates of productivity). But it became clear to them that the same technologies making many jobs safer, easier, and more productive were also reducing the demand for many types of human workers.

Decoupling Productivity and Employment

Digital technologies have boosted productivity in the United States without also spurring the expected job growth, argue Erik Brynjolfsson and Andrew McAfee. A result of this decoupling is that while gross domestic product (GDP) has risen, median income has not, and inequality has grown.

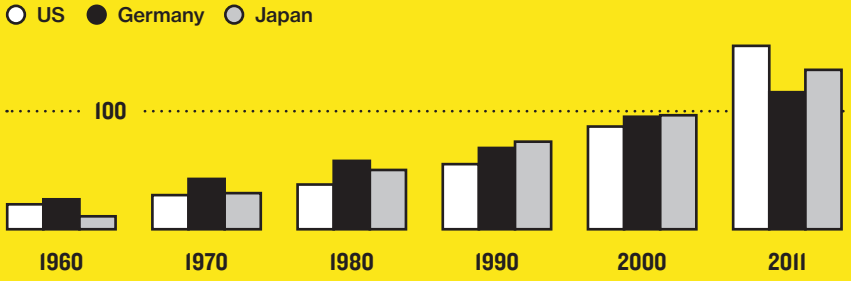
U.S. productivity and employment

Beginning in 2000, a widening gap between productivity and private employment showed up in federal labor statistics (indexed: 1947 = 100).



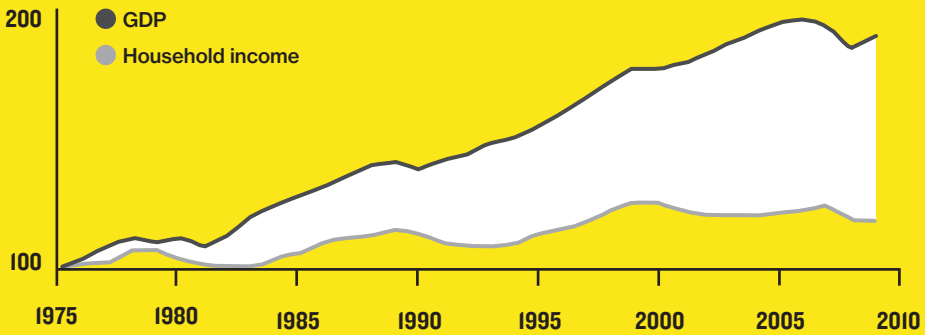
Output per employed person in manufacturing

In leading advanced manufacturing countries, output per worker has grown impressively as factories have become more automated (indexed: 2002 = 100).



U.S. GDP per capita and household income

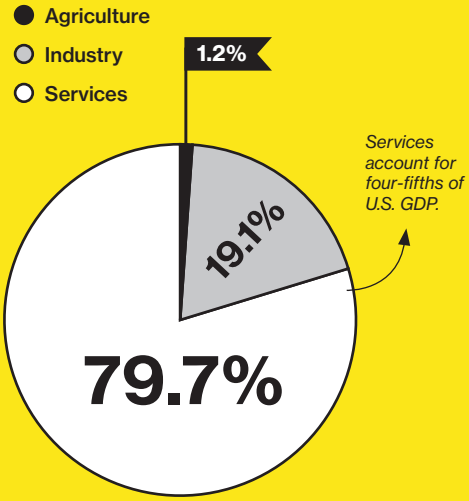
While the nation's total output has generally grown over the last 25 years, the median household income has been nearly stagnant (indexed: 1975 = 100).



320k Industrial robots sold in the last two years

Automation in services has a dramatic effect

Making service work more efficient has an outsize impact on productivity figures because the sector is so large.



Anecdotal evidence that digital technologies threaten jobs is, of course, everywhere. Robots and advanced automation have been common in many types of manufacturing for decades. In the United States and China, the world's manufacturing powerhouses, fewer people work in manufacturing today than in 1997, thanks at least in part to automation. Modern automotive plants, many of which were transformed by industrial robotics in the 1980s, routinely use machines that autonomously weld and paint body parts—tasks that were once handled by humans. Most recently, industrial robots like Rethink Robotics' Baxter (see "The Blue-Collar Robot," May/June 2013), more flexible and far cheaper than their predecessors, have been introduced to perform simple jobs for small manufacturers in a variety of sectors. The website of a Silicon Valley startup called Industrial Perception features a video of the robot it has designed for use in warehouses picking up and throwing boxes like a bored elephant. And such sensations as Google's driverless car suggest what automation might be able to accomplish someday soon.

A less dramatic change, but one with a potentially far larger impact on employment, is taking place in clerical work and professional services. Technologies like the Web, artificial intelligence, big data, and improved analytics—all made possible by the ever increasing availability of cheap computing power and storage capacity—are automating many routine tasks. Countless traditional white-collar jobs, such as many in the post office and in customer service, have disappeared. W. Brian Arthur, a visiting researcher at the Xerox Palo Alto Research Center's intelligence systems lab and a former economics professor at Stanford University, calls it the "autonomous economy." It's far more subtle than the idea of robots and automation doing human jobs, he says: it involves "digital processes talking to other digital processes and creating new processes," enabling us to do many things with fewer people and making yet other human jobs obsolete.

It is this onslaught of digital processes, says Arthur, that primarily explains how productivity has grown without a significant increase in human labor. And, he says, "digital versions of human intelligence" are increasingly replacing even those jobs once thought to require people. "It will change every profession in ways we have barely seen yet," he warns.

McAfee, associate director of the MIT Center for Digital Business at the Sloan School of Management, speaks rapidly and with a certain awe as he describes advances such as Google's driverless car. Still, despite his obvious enthusiasm for the technologies, he doesn't see the recently vanished jobs coming back. The pressure on employment and the resulting inequality will only get worse, he suggests, as digital technologies—fueled with "enough computing power, data, and geeks"—continue their exponential advances over the next several decades. "I would like to be wrong," he says, "but when all these science-fiction technologies are deployed, what will we need all the people for?"

NEW ECONOMY?

But are these new technologies really responsible for a decade of lackluster job growth? Many labor economists say the data are, at best, far from conclusive. Several other plausible explanations, including events related to global trade and the financial crises of the early and late 2000s, could account for the relative slowness of job creation since the turn of the century. "No one really knows," says Richard Freeman, a labor economist at Harvard University. That's because it's very difficult to "extricate" the effects of technology from other macroeconomic effects, he says. But he's skeptical that technology would change a wide range of business sectors fast enough to explain recent job numbers.

David Autor, an economist at MIT who has extensively studied the connections between jobs and technology, also doubts that technology could account for such an abrupt change in total employment. "There was a great sag in employment beginning in 2000. Something did change," he says. "But no one knows the cause." Moreover, he doubts that productivity has, in fact, risen robustly in the United States in the past decade (economists can disagree about that statistic because there are different ways of measuring and weighing economic inputs and outputs). If he's right, it raises the possibility that poor job growth could be simply a result of a sluggish economy. The sudden slowdown in job creation "is a big puzzle," he says, "but there's not a lot of evidence it's linked to computers."

Employment trends have polarized the workforce and hollowed out the middle class.

To be sure, Autor says, computer technologies are changing the types of jobs available, and those changes "are not always for the good." At least since the 1980s, he says, computers have increasingly taken over such tasks as bookkeeping, clerical work, and repetitive production jobs in manufacturing—all of which typically provided middle-class pay. At the same time, higher-paying jobs requiring creativity and problem-solving skills, often aided by computers, have proliferated. So have low-skill jobs: demand has increased for restaurant workers, janitors, home health aides, and others doing service work that is nearly impossible to automate. The

DATA FROM THE BUREAU OF LABOR STATISTICS (PRODUCTIVITY, EMPLOYMENT, OUTPUT, GDP PER CAPITA); INTERNATIONAL FEDERATION OF ROBOTICS; CIA WORLD FACTBOOK (GDP BY SECTOR)

result, says Autor, has been a "polarization" of the workforce and a "hollowing out" of the middle class—something that has been happening in numerous industrialized countries for the last several decades. But "that is very different from saying technology is affecting the total number of jobs," he adds. "Jobs can change a lot without there being huge changes in employment rates."

What's more, even if today's digital technologies are holding down job creation, history suggests that it is most likely a temporary, albeit painful, shock; as workers adjust their skills and entrepreneurs create opportunities based on the new technologies, the number of jobs will rebound. That, at least, has always been the pattern. The question, then, is whether today's computing technologies will be different, creating long-term involuntary unemployment.

At least since the Industrial Revolution began in the 1700s, improvements in technology have changed the nature of work and destroyed some types of jobs in the process. In 1900, 41 percent of Americans worked in agriculture; by 2000, it was only 2 percent. Likewise, the proportion of Americans employed in manufacturing has dropped from 30 percent in the post–World War II years to around 10 percent today—partly because of increasing automation, especially during the 1980s.

While such changes can be painful for workers whose skills no longer match the needs of employers, Lawrence Katz, a Harvard economist, says that no historical pattern shows these shifts leading to a net decrease in jobs over an extended period. Katz has done extensive research on how technological advances have affected jobs over the last few centuries—describing, for example, how highly skilled artisans in the mid-19th century were displaced by lower-skilled workers in factories. While it can take decades for workers to acquire the expertise needed for new types of employment, he says, "we never have run out of jobs. There is no long-term trend of eliminating work for people. Over the long term, employment rates are fairly stable. People have always been able to create new jobs. People come up with new things to do."

Still, Katz doesn't dismiss the notion that there is something different about today's digital technologies—something that could affect an even broader range of work. The question, he says, is whether economic history will serve as a useful guide. Will the job disruptions caused by technology be temporary as the workforce adapts, or will we see a science-fiction scenario in which automated processes and robots with superhuman skills take over a broad swath of human tasks? Though Katz expects the historical pattern to hold, it is "genuinely a question," he says. "If technology disrupts enough, who knows what will happen?"

DR. WATSON

To get some insight into Katz's question, it is worth looking at how today's most advanced technologies are being deployed in industry. Though these technologies have undoubtedly taken over some human jobs, finding evidence of workers being displaced by machines on a large scale is not all that easy. One reason it is difficult to pinpoint the net impact on jobs is that automation is often used to make human workers more efficient, not necessarily to replace them. Rising productivity means businesses can do the same work with fewer employees, but it can also enable the businesses to expand production with their existing workers, and even to enter new markets.

Take the bright-orange Kiva robot, a boon to fledgling e-commerce companies. Created and sold by Kiva Systems, a startup that was founded in 2002 and bought by Amazon for $775 million in 2012, the robots are designed to scurry across large warehouses, fetching racks of ordered goods and delivering the products to humans who package the orders. In Kiva's large demonstration warehouse and assembly facility at its headquarters outside Boston, fleets of robots move about with seemingly endless energy: some newly assembled machines perform tests to prove they're ready to be shipped to customers around the world, while others wait to demonstrate to a visitor how they can almost instantly respond to an electronic order and bring the desired product to a worker's station.

A warehouse equipped with Kiva robots can handle up to four times as many orders as a similar unautomated warehouse, where workers might spend as much as 70 percent of their time walking about to retrieve goods. (Coincidentally or not, Amazon bought Kiva soon after a press report revealed that workers at one of the retailer's giant warehouses often walked more than 10 miles a day.)

Despite the labor-saving potential of the robots, Mick Mountz, Kiva's founder and CEO, says he doubts the machines have put many people out of work or will do so in the future. For one thing, he says, most of Kiva's customers are e-commerce retailers, some of them growing so rapidly they can't hire people fast enough. By making distribution operations cheaper and more efficient, the robotic technology has helped many of these retailers survive and even expand. Before founding Kiva, Mountz worked at Webvan, an online grocery delivery company that was one of the 1990s dot-com era's most infamous flameouts. He likes to show the numbers demonstrating that Webvan was doomed from the start; a $100 order cost the company $120 to ship. Mountz's point is clear: something as mundane as the cost of materials handling can consign a new business to an early death. Automation can solve that problem.

Meanwhile, Kiva itself is hiring. Orange balloons—the same color as the robots—hover over multiple cubicles in its sprawling office, signaling that the occupants arrived within the last month. Most of these new

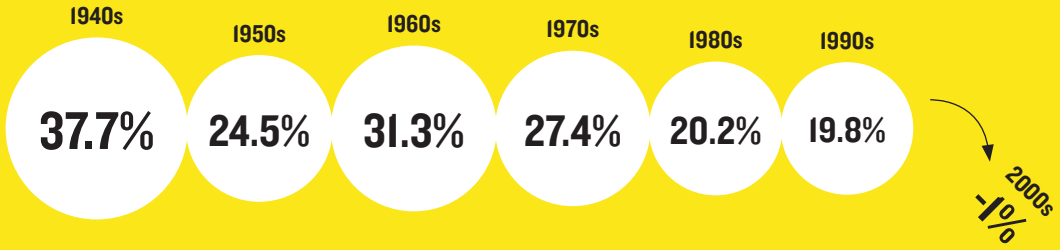
DATA FROM THE BUREAU OF LABOR STATISTICS (JOB GROWTH, MANUFACTURING EMPLOYMENT), D. AUTOR AND D. DORN, U.S. CENSUS, AMERICAN COMMUNITY SURVEY, AND DEPARTMENT OF LABOR (CHANGE IN EMPLOYMENT AND WAGES BY SKILL, ROUTINE JOBS)

Where the Jobs Are Going

There is plenty of evidence that technological advances are affecting what jobs are in demand. High-skill positions that often take advantage of computers are growing, as are low-skill jobs doing work, such as home health care, that is difficult to automate. Many mid-skill jobs, however, are disappearing.

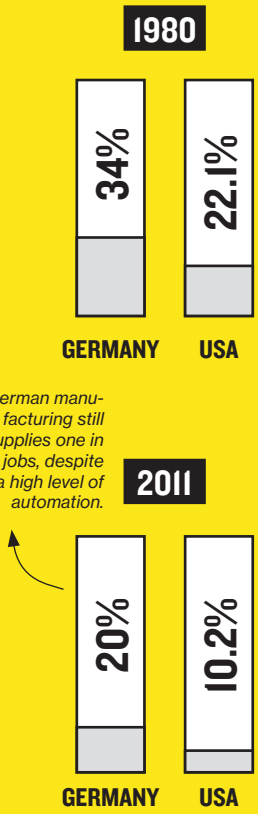
U.S. job growth by decade

The percentage change in nonfarm employment through the last seven decades illustrates just how dismal job prospects have been since 2000.



Manufacturing employment

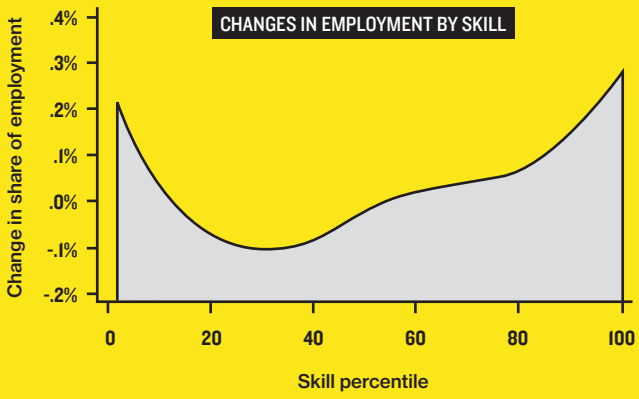
Employment in manufacturing now accounts for only one in 10 jobs in the United States. Germany, a manufacturing powerhouse, has fared somewhat better.



German manufacturing still supplies one in five jobs, despite a high level of automation.

Hollowing out the middle

Research by MIT economist David Autor shows that between 1980 and 2005, the middle class suffered both in share of jobs and in wage growth. The top chart shows share of employment held by workers of different skill levels; the bottom shows changes in wages.



The mix of jobs

The fastest-growing jobs in the U.S. from 2000 to 2010 reflect the demand for highly technical skills and those lower-skill jobs that are hard to automate. Highly routine jobs are especially vulnerable to automation.

FASTEST-GROWING JOBS

1. Software engineers-applications
2. Computer support workers
3. Software engineers-systems
4. Network administrators
5. Network systems analysts
6. Desktop publishers
7. Database administrators
8. Personal and home care aides
9. Computer systems analysts
10. Medical assistants

VULNERABLE JOBS?

1. Butchers
2. Secretaries and stenographers
3. Payroll clerks
4. Bank tellers
5. File clerks
6. Cashiers
7. Typists
8. Pharmacists
9. Bookkeepers
10. Postal clerks

employees are software engineers: while the robots are the company's poster boys, its lesser-known innovations lie in the complex algorithms that guide the robots' movements and determine where in the warehouse products are stored. These algorithms help make the system adaptable. It can learn, for example, that a certain product is seldom ordered, so it should be stored in a remote area.

Though advances like these suggest how some aspects of work could be subject to automation, they also illustrate that humans still excel at certain tasks—for example, packaging various items together. Many of the traditional problems in robotics—such as how to teach a machine to recognize an object as, say, a chair—remain largely intractable and are especially difficult to solve when the robots are free to move about a relatively unstructured environment like a factory or office.

Techniques using vast amounts of computational power have gone a long way toward helping robots understand their surroundings, but John Leonard, a professor of engineering at MIT and a member of its Computer Science and Artificial Intelligence Laboratory (CSAIL), says many familiar difficulties remain. "Part of me sees accelerating progress; the other part of me sees the same old problems," he says. "I see how hard it is to do anything with robots. The big challenge is uncertainty." In other words, people are still far better at dealing with changes in their environment and reacting to unexpected events.

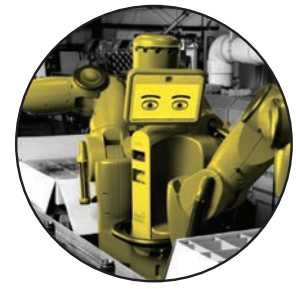
For that reason, Leonard says, it is easier to see how robots could work *with* humans than on their own in many applications. "People and robots working together can happen much more quickly than robots simply replacing humans," he says. "That's not going to happen in my lifetime at a massive scale. The semiautonomous taxi will still have a driver."

Even if the economy is only going through a transition, it is an extremely painful one for many.

One of the friendlier, more flexible robots meant to work with humans is Rethink's Baxter. The creation of Rodney Brooks, the company's founder, Baxter needs minimal training to perform simple tasks like picking up objects and moving them to a box. It's meant for use in relatively small manufacturing facilities where conventional industrial robots would cost too much and pose too much danger to workers. The idea, says Brooks, is to have the robots take care of dull, repetitive jobs that no one wants to do.

It's hard not to instantly like Baxter, in part because it seems so eager to please. The "eyebrows" on its display rise quizzically when it's puzzled; its arms submissively and gently retreat when bumped. Asked about the claim that such advanced industrial robots could eliminate jobs, Brooks answers simply that he doesn't see it that way. Robots, he says, can be to factory workers as electric drills are to construction workers: "It makes them more productive and efficient, but it doesn't take jobs."

The machines created at Kiva and Rethink have been cleverly designed and built to work with people, taking over the tasks that the humans often don't want to do or aren't especially good at. They are specifically designed to enhance these workers' productivity. And it's hard to see how even these increasingly sophisticated robots will replace humans in most manufacturing and industrial jobs anytime soon. But clerical and some professional jobs could be more vulnerable. That's because the marriage of artificial intelligence and big data is beginning to give machines a more humanlike ability to reason and to solve many new types of problems.



BAXTER

Rethink Robotics' Baxter is a robot meant to work with people in smaller manufacturing facilities. Its expressive eyes reveal what the robot is "looking" at and let a nearby human know if it's confused.

KIVA

A Kiva Systems robot can scurry about the floor of a large warehouse to find ordered products. It then fetches the correct rack or pallet and brings it to a worker who packages the goods.

WATSON

IBM's Watson, the computer that won at Jeopardy! *in 2011, combines artificial intelligence with big data and natural-language processing to advise doctors or callers to customer-support lines.*

In the tony northern suburbs of New York City, IBM Research is pushing supersmart computing into the realms of such professions as medicine, finance, and customer service. IBM's efforts have resulted in Watson, a computer system best known for beating human champions on the game show *Jeopardy!* in 2011. That version of Watson now sits in a corner of a large data center at the research facility in Yorktown Heights, marked with a glowing plaque commemorating its glory days. Meanwhile, researchers there are already testing new generations of Watson in medicine, where the technology could help physicians diagnose diseases like cancer, evaluate patients, and prescribe treatments.

IBM likes to call it cognitive computing. Essentially, Watson uses artificial-intelligence techniques, advanced natural-language processing and analytics, and massive amounts of data drawn from sources specific to a given application (in the case of health care, that means medical journals, textbooks, and information collected from the physicians or hospitals using the system). Thanks to these innovative techniques and huge amounts of computing power, it can quickly come up with "advice"—for example, the most recent and relevant information to guide a doctor's diagnosis and treatment decisions.

Despite the system's remarkable ability to make sense of all that data, it's still early days for Dr. Watson. While it has rudimentary abilities to "learn" from specific patterns and evaluate different possibilities, it is far from having the type of judgment and intuition a physician often needs. But IBM has also announced it will begin selling Watson's services to customer-support call centers, which rarely require human judgment that's quite so sophisticated. IBM says companies will rent an updated version of Watson for use as a "customer service agent" that responds to questions from consumers; it has already signed on several banks. Automation is nothing new in call centers, of course, but Watson's improved capacity for natural-language processing and its ability to tap into a large amount of data suggest that this system could speak plainly with callers, offering them specific advice on even technical and complex questions. It's easy to see it replacing many human holdouts in its new field.

DIGITAL LOSERS

The contention that automation and digital technologies are partly responsible for today's lack of jobs has obviously touched a raw nerve for many worried about their own employment. But this is only one consequence of what Brynjolfsson and McAfee see as a broader trend. The rapid acceleration of technological progress, they say, has greatly widened the gap between economic winners and losers—the income inequalities that many economists have worried about for decades. Digital technologies tend to favor "superstars," they point out. For example, someone who creates a computer program to automate tax preparation might earn millions or billions of dollars while eliminating the need for countless accountants.

New technologies are "encroaching into human skills in a way that is completely unprecedented," McAfee says, and many middle-class jobs are right in the bull's-eye; even relatively high-skill work in education, medicine, and law is affected. "The middle seems to be going away," he adds. "The top and bottom are clearly getting farther apart." While technology might be only one factor, says McAfee, it has been an "underappreciated" one, and it is likely to become increasingly significant.

Not everyone agrees with Brynjolfsson and McAfee's conclusions—particularly the contention that the impact of recent technological change could be different from anything seen before. But it's hard to ignore their warning that technology is widening the income gap between the tech-savvy and everyone else. And even if the economy is only going through a transition similar to those it's endured before, it is an extremely painful one for many workers, and that will have to be addressed somehow. Harvard's Katz has shown that the United States prospered in the early 1900s in part because secondary education became accessible to many people at a time when employment in agriculture was drying up. The result, at least through the 1980s, was an increase in educated workers who found jobs in the industrial sectors, boosting incomes and reducing inequality. Katz's lesson: painful long-term consequences for the labor force do not follow inevitably from technological changes.

Brynjolfsson himself says he's not ready to conclude that economic progress and employment have diverged for good. "I don't know whether we can recover, but I hope we can," he says. But that, he suggests, will depend on recognizing the problem and taking steps such as investing more in the training and education of workers.

"We were lucky and steadily rising productivity raised all boats for much of the 20th century," he says. "Many people, especially economists, jumped to the conclusion that was just the way the world worked. I used to say that if we took care of productivity, everything else would take care of itself; it was the single most important economic statistic. But that's no longer true." He adds, "It's one of the dirty secrets of economics: technology progress does grow the economy and create wealth, but there is no economic law that says everyone will benefit." In other words, in the race against the machine, some are likely to win while many others lose.

David Rotman is the editor of MIT Technology Review.

FROM TOP: COURTESY OF RETHINK ROBOTICS; BETH HALL/BLOOMBERG NEWS; BEN HIDER/GETTY IMAGES

The World as Free-Fire Zone

How drones made it easy for Americans to kill a particular person anywhere on the planet.

By Fred Kaplan

THE UNMANNED AERIAL VEHICLE—THE "DRONE," the very emblem of American high-tech weaponry—started out as a toy, the fusion of a model airplane and a lawn-mower engine. While its original purpose was to bust up Soviet tanks in the first volleys of World War III, it has evolved into the favored technology for targeted assassinations in the global war on terror. Its use has sparked a great debate—at first within the most secret parts of the government, but in recent months among the general public—over the tactics, strategy, and morality not only of drone warfare but of modern warfare in general.

But before this debate can go much further—before Congress or other branches of government can lay down meaningful standards or ask pertinent questions—distinctions must be drawn, myths punctured, real issues teased out from misinformed or misleading distractions.

AFP

A little history is helpful. The drone as we know it today was the brainchild of John Stuart Foster Jr., a nuclear physicist, former head of the Lawrence Livermore National Laboratory (then called the Lawrence Radiation Laboratory), and—in 1971, when the idea occurred to him—the director of defense research and engineering, the top scientific post in the Pentagon. Foster was a longtime model-airplane enthusiast, and one day he realized that his hobby could make for a new kind of weapon. His idea: take an unmanned, remote-controlled airplane, strap a camera to its belly, and fly it over enemy targets to snap pictures or shoot film; if possible, load it with a bomb and destroy the targets, too.

Two years later, the Defense Advanced Research Projects Agency (DARPA) built two prototypes based on Foster's concept, dubbed Praeire and Calere. Weighing 75 pounds and powered by a modified lawn-mower engine, each vehicle could stay aloft for two hours while hoisting a 28-pound payload.

Pentagon agencies design lots of prototypes; most of them never get off the drawing board. Foster's idea became a real weapon because it converged with a new defense doctrine. In the early-to-mid 1970s, the Soviet Union was beefing up its conventional military forces along the border between East and West Germany. A decade earlier, U.S. policy was to deter an invasion of Western Europe by threatening to retaliate with nuclear weapons. But now, the Soviets had amassed their own sizable nuclear arsenal. If we nuked them, they could nuke us back. So DARPA commissioned a study to identify new technologies that might give the president "a variety of response options" in the event of a Soviet invasion, including "alternatives to massive nuclear destruction."

The study was led by Albert Wohlstetter, a former strategist at the RAND Corporation, who in the 1950s and '60s wrote highly influential briefings and articles on the nuclear balance of power. The analyst pored over various projects that DARPA had on its books and figured that Foster's unmanned airplanes might fit the bill. In the previous few years, the U.S. military had developed a number of "precision-guided munitions"—products of the microprocessor revolution—that could land within a few meters of a target. Wohlstetter proposed putting the munitions on Foster's pilotless planes and using them to hit targets deep behind enemy lines—Soviet tank echelons, air bases, ports. In the past, these sorts of targets could have been destroyed only by nuclear weapons, but a small bomb that hits within a few feet of its target can do as much damage as a very large bomb (even a low-yield nuclear bomb) that misses its target by a few thousand feet.

By the end of the 1970s, DARPA and the U.S. Army had begun testing a new weapon called Assault Breaker, which was directly inspired by Wohlstetter's study. Soon, a slew of super-accurate weapons—guided by laser beams, radar emissions, millimeter waves, or, later (and more accurately), the signals of global positioning satellites—poured into the U.S. arsenal. The Army's Assault Breaker was propelled by an artillery rocket; the first Air Force and Navy versions, called Joint Direct Attack Munitions (JDAMs), were carried under the wings, and launched from the cockpits, of manned fighter jets.

Something close to Foster's vision finally materialized in the mid-1990s, during NATO's air war over the Balkans, with an unmanned aerial vehicle (UAV) called the Predator. It could loiter for 24 hours at an altitude of 25,000 feet, carrying a 450-pound payload. In its first incarnation, it was packed only with video and communications gear. The digital images taken by the camera were beamed to a satellite and then transmitted to a ground station thousands of miles away, where operators controlled the drone's flight path with a joystick while watching its real-time video stream on a monitor.

In February 2001, the Pentagon and CIA conducted the first test of a modified Predator, which carried not only a camera but also a laser-guided Hellfire missile. The Air Force mission statement for this armed UAV noted that it would be ideal for hitting "fleeting and perishable" targets. In an earlier era, this phrase would have meant destroying tanks on a battlefield. In the opening phase of America's new war on terror, it meant hunting and killing jihadists, especially Osama bin Laden and his lieutenants in al-Qaeda.

And so a weapon designed at the height of the Cold War to impede a Soviet armor assault on the

Editor's Note: *This story relies upon anonymous sources who could not have spoken on the record without prosecution or other serious repercussions. The author revealed their identities to* MIT Technology Review.

plains of Europe evolved into a device for killing bands of stateless terrorists—or even an individual terrorist—in the craggy mountains of South Asia. In this sense, drones have hovered over U.S. military policy for more than three decades, the weapons and the policy shifting in tandem over time.

A War without Boundaries

HOW THIS CAME ABOUT IS ANOTHER FAR-FROM-inevitable story. The rise of the drone met serious resistance from one powerful quarter: the senior officer corps of the United States Air Force, the same organization that developed the weapon. The dominant culture in each of the armed services—the traits that are valued, the kinds of officers who get promoted—is shaped by its big-ticket weapons systems. Thus, from 1947 to 1981, every Air Force chief of staff rose through the ranks as a nuclear bombardier in Strategic Air Command. For the next quarter-century, as spending on conventional forces soared, every chief of staff had been a fighter pilot in Tactical Air Command.

By the fall of 2009, the Air Force was training more drone-joystick pilots than airplane pilots. It was the start of a new era.

That's where things stood in 2003, when President George W. Bush ordered the invasion of Iraq. As liberation became an occupation, which sparked an insurgency and then a sectarian civil war, U.S. commanders on the ground requested support from those shiny new Predator drones. The most lethal threat to American soldiers and Marines was the improvised explosive device, or roadside bomb. A drone's camera in the sky could see an insurgent planting the IED and follow him back to his hideout. But drones (slow, unmanned hovering planes) were anathema to the dominant Air Force culture (which cherished fast, manned jet fighters). So the Air Force generals turned down or ignored the Army and Marine commanders' pleas for more drones.

All this changed in 2006, when Bush named Robert Gates to replace Donald Rumsfeld as secretary of defense. Gates came into the Pentagon with one goal: to clean up the mess in Iraq. He was shocked that the generals in the three big services cared more about high-tech weapons for the wars of the future than the needs of the war they were fighting. He was particularly appalled by the Air Force generals' hostility toward drones. Gates boosted production; the generals slowed down delivery. He accelerated delivery; they held up deployment. He fired the Air Force chief of staff, General T. Michael Moseley (ostensibly for some other act of malfeasance but really because of his resistance to UAVs), and appointed in his place General Norton Schwartz, who had risen as a gunship and cargo-transport pilot in special operations forces. Just before his promotion, Schwartz had been head of the U.S. Transportation Command—that is, he was in charge of rushing supplies to soldiers and Marines. As the new chief, Schwartz placed high priority on shipping drones to the troops in Iraq—and over the next few years, he turned the drone-joystick pilots into an elite cadre of the Air Force.

By the fall of 2009, toward the end of Barack Obama's first year as president, the Air Force was training more drone-joystick pilots than airplane-cockpit pilots. It was the start of a new era, not only for Air Force culture but also for the American way of war.

That year, 2009, saw not just a surge in U.S. drone strikes—in part because more drones were available and the institutional resistance to them had evaporated—but also a shift in where those strikes took place. There was nothing politically provocative about drones in Iraq or Afghanistan. They were weapons of war, used mainly for close air support of U.S. ground troops in countries where those troops were fighting wars. The controversy—which persists today—began when drones started hunting and killing specific people in countries where the United States was not officially at war.

These strikes took place mainly in Pakistan and Yemen. Pakistan was serving as a sanctuary for Taliban fighters in neighboring Afghanistan; Yemen was emerging as the center of a new wing of al-Qaeda in the Arabian Peninsula. Bush had ordered a few strikes in those countries: in fact, the first drone strike outside a formal war zone took place in Yemen, on November 3, 2002, against an al-Qaeda leader who a few years earlier had helped plan the attack on the USS *Cole*. Bush also launched 48 drone strikes in the Waziristan region of Pakistan, along the mountainous border with Afghanistan—36 of them during his last year in office.

Obama, who had pledged during the 2008 presidential campaign to get out of Iraq and deeper into Afghanistan, accelerated this trend, launching 52 drone strikes on Pakistani territory just in his first year. In 2010 he more than doubled the number of these strikes, to 122. Then, the next year, the number fell off, to 73. In 2012 it declined further, to 48—which still equaled the total number of strikes in all eight years of Bush's presidency. In a contrary shift, 2012 was also the year when the number of drone strikes soared in Yemen, from a mere handful to 54.

These strikes have provoked violent protest in those countries, alienating even those who'd previously felt no affection for jihadists and, in some cases, provided some support for the United States. At home, a political and legal debate rages over the wisdom and propriety of drone strikes as a tool in the war on terror.

The most common criticism is that drones often wind up killing civilians. This is true, but it's hardly unique to drones.

Heightening the controversy is the fact that everything about these strikes outside war zones—including, until recently, their occurrence—is secret. Drone strikes in Iraq and Afghanistan, like all other military operations, have been conducted by the Defense Department. But drone strikes elsewhere are covert operations conducted by the Central Intelligence Agency, which operates in the dark (even congressional oversight is limited to the members of the select intelligence committees) and under a different, more permissive legal authority (Title 50 of the U.S. Code, not the Defense Department's Title 10).

President Obama has begun to address these protests and concerns, to some extent. (This may be why, as of late May, the United States had launched only 13 drone strikes in Pakistan in 2013.) Still, some of the protests are more valid—and some of Obama's actions less responsive—than others.

An Arrogant Sort of Warfare

THE MOST COMMON CRITICISM OF DRONE STRIKES is that even when they're aimed at military targets (terrorists, insurgent safe houses, etc.), they often wind up killing civilians. This is true, but it's hardly unique to drones. In fact, drones cause far fewer civilian casualties than other kinds of air strikes. The weapons they carry are very small and accurate. The laser-guided Hellfire missile and GPS-guided Small Diameter Bomb land within a few feet of their targets and explode with the force of a mere 30 to 100 pounds of TNT. Aerial bombs in the past have been much larger and far less accurate.

Peter Bergen of the New America Foundation, who has made a thorough study of the publicly available data, estimates that from 2004 to mid-May of 2013, drone strikes killed between 258 and 307 civilians in Pakistan. That's 7 to 15 percent of the total fatalities caused by drones in the country. Civilian fatalities in Yemen are harder to estimate, but they seem to make up about 8 percent of a much smaller total death toll. These are hardly numbers to wave away casually, but the weapons of a generation ago would have killed many more.

And yet seen from a different angle, this comparison is nearly irrelevant, and the numbers appear to be quite high. For when we talk about accidental civilian deaths by drones in Pakistan and Yemen, we are talking about countries where the United States is not officially fighting wars. In other words, these are countries where the people killed—and their embittered friends and relatives—didn't know that they were living in a war zone. Imagine that Mexican commanders launched an air strike on a border town in California because their enemies were hiding there and that, as a result of poor aim or bad intelligence or dumb luck, a few dozen American citizens were killed. The American people and the U.S. government would be outraged, and justifiably so.

Drone strikes are criticized as an arrogant sort of warfare. The whole idea of killing people from far away, invisibly and without risk of retaliation, seems somehow unfair. But the same was said when the British and Americans dropped bombs from airplanes in World War II. It was said when British archers used longbows against French knights. It's natural for armies to find ways to maximize the enemy's losses while minimizing their own.

Still, these comparisons don't quite fit. Drones *are* different, because of where they are used. Stanley McChrystal, a retired general who relied heavily on drone strikes when he was special-ops chief in Iraq and commander of all NATO forces in Afghanistan, put it this way in a recent interview with Reuters: "The resentment caused by American use of unmanned

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strikes ... is much greater than the average American appreciates. They are hated on a visceral level, even by people who've never seen one or seen the effects of one."

This isn't a speculative matter. In April, at hearings before the Senate Judiciary Committee (the first public hearings on the consequences of drones), Farea al-Muslimi, a Yemeni activist and journalist, testified about a drone strike in his native village just a week earlier. Before the strike, al-Muslimi said, the villagers had a positive impression of the United States, drawn mainly from conversations with him about the year he'd spent here during high school, which he described as "one of the best years of my life." But now, he went on, "when they think of America, they think of the terror they feel from the drones that hover over their heads, ready to fire missiles at any time."

In a conventional war, this might be a regrettable side effect. But in the kinds of wars the United States has been fighting lately, in Yemen and elsewhere, it feeds into the main effect. These are wars against guerrillas, insurgents, terrorists, rogues, fought not only to kill the enemy but to influence the population (to "win hearts and minds," as the old saying had it). If the most prominent weapon in this war alienates the people who live under its shadow—in some cases driving them into the arms of the enemy, either for protection or on the principle that the enemy of their enemy is their friend—then it is a lousy weapon. Retired general David Petraeus, in his 2006 U.S. Army field manual on counterinsurgency, made a similar point: "An operation that kills five insurgents is counterproductive if collateral damage leads to the recruitment of 50 more insurgents."

Even so, as Petraeus noted, sometimes a commander has to fire the weapon regardless of the possible backlash; sometimes the target is too important, the threat too dangerous, to pass by. But here we come to another source of controversy about drones. As the strikes have evolved over the years, fewer and fewer of their targets have posed a genuine threat to the United States. In more and more instances, the targets of drone strikes are low-level militiamen, not terrorist leaders. In a striking number of cases, they are targeted for death even though their identities—their names, ranks, and the scope of their involvement in a terrorist organization—are unknown.

More and more, the drones are used for "signature strikes." The officer or official approving a strike might not know who its targets are, but their behavior—as picked up by drone cameras, satellites, cell-phone intercepts, spies on the ground, or other "sources and methods" of intelligence agencies—strongly suggests that they're active members of some organization whose leaders would be the natural targets of a drone strike. For instance, they might be moving in and out of a building that's a known terrorist hangout, or they might be training at a known terrorist facility. In other words, their behavior bears the "signature" of a legitimate target.

Neither the Bush nor the Obama administration has ever confirmed the existence of signature strikes. (Like all CIA drone strikes, they are highly classified.) But one knowledgeable official told me that in Pakistan, the "vast majority" of drone strikes have been signature strikes—from the very beginning up until now.

There seems to be no formal list of the criteria that a suspected terrorist must meet before he can be targeted by a drone. Nor is there some quantitative technique for measuring an official's degree of confidence in this signature. Those who pick the targets have a database of correlations between certain types of behavior and the presence of terrorist leaders. But it's a judgment call, and there's usually no way—or desire—to check afterward whether the judgment was good or bad. The practice evolved gradually from tactics in Iraq and Afghanistan. It made sense in a war zone. An officer sees a sniper on a rooftop, or someone planting an IED along a road, or armed men moving in and out of a known bomb factory. Almost certainly, they're enemy combatants in a war. He doesn't need to know their names; nor does it much matter whether they're killed by a bullet, a mortar, a smart bomb from a helicopter, or a Hellfire missile from a drone.

But outside a war zone, such questions do matter. Attacks in those areas amount to assassinations—which, besides the political backlash they may inspire locally, are prohibited by U.S. and international law.

President Obama is aware of this; he was trained as a constitutional lawyer. In a speech on national security on May 23, he laid out three conditions that must be met before a drone strike can be approved. He said it must be determined that the target poses a "continuing, imminent threat" against the United States; that capturing the person alive is infeasible; and that there is "near certainty" that the strike will kill or injure no civilians.

These conditions were nothing new. They came from a 16-page Justice Department white paper that was leaked to the press in February. The white paper's legal rationale was full of holes and evasions, and so was the speech it inspired.

The white paper's main sleight of hand was to define the terms in such a way that the most basic fact about these attacks—that they're conducted outside a war zone—is denied. To this end, it cites the Authorization for Use of Military Force, a joint resolution passed by Congress on September 14, 2001 (three days after the terrorist attacks on the World Trade Center and the Pentagon). Under the AUMF, the president may

> use all necessary and appropriate force against those nations, organizations, or persons he determines planned, authorized, committed, or aided the terrorist attacks that occurred on September 11, 2001, or harbored such organizations or persons, in order to prevent any future acts of international terrorism against the United States by such nations, organizations or persons.

It turns out that most of the people killed by drones are not al-Qaeda leaders. Often they're not affiliated with al-Qaeda at all.

This language is strikingly broad. Nothing is mentioned about geography. The premise is that al-Qaeda and its affiliates threaten U.S. security; so the president can attack its members, regardless of where they happen to be. Taken literally, the resolution turns the world into a free-fire zone.

The white paper then lays down the same three conditions that Obama later recited—ostensibly to impose restrictions on otherwise sweeping executive authority. In fact, they restrict nothing. Key to this legalistic gamesmanship is the paper's definition of "imminent threat." It states:

> The condition that an operational leader [of al-Qaeda or an affiliated organization] presents an "imminent" threat of violent attack against the United States does not require the United States to have clear evidence that a specific attack … will take place in the immediate future.

In other words, "imminent," in this context, does not mean imminent.

The paper's logic is that leaders of al-Qaeda and its affiliates are "continually planning attacks" against the United States. "By its nature, therefore," the threat demands "a broader concept of imminence." That is to say, the threat of an attack is constant; it is always vaguely imminent, even if there are no signs of an actual attack. And so the first condition that must be met for a targeted assassination—an imminent threat of attack—is not a restriction in any real sense.

The second condition—that it must be infeasible to take the terrorist alive—is equally meaningless. Because the threat of attack is always imminent, the United States is likely to have "only a limited window of opportunity" for mobilizing a raid on the ground. By this standard, it is *always* infeasible to capture a terrorist. Therefore, once he is found, it is necessary to kill him with a drone strike. Again, it's a test that, by design, cannot be failed.

Lax as these standards are, the United States has not lived up to them. For it turns out that most of the people killed by drones, in places like Yemen and Pakistan, are not al-Qaeda leaders. Often they're not affiliated with al-Qaeda at all.

In April, Jonathan Landay of McClatchy Newspapers wrote a story summarizing top-secret CIA reports on the results of drone strikes conducted in Pakistan over a 12-month period ending in September 2011. More than half the people that the CIA intentionally killed—at least 265 of the 482 targeted—were "assessed" as simply extremists of Afghan, Pakistani, or unknown origin. Many of them were members of the Haqqani Network. The Haqqani have ties with Pakistan's intelligence service and fight alongside some insurgent factions in Afghanistan—but they have never planned attacks outside the region. During this period, only six of the people killed by drones were top al-Qaeda leaders.

In short, even accepting the white paper's circular logic, the majority of those strikes fell outside the legally permissible boundaries. They were not aimed at terrorist leaders who pose a threat, imminent or otherwise, against the United States.

The third and final condition for drone strikes outside war zones—that steps must be taken to minimize or avoid civilian casualties—is a real restriction. Officials involved in these operations have told me (on condition of anonymity) that on several occasions strikes have been called off for this very reason, even if the

target was in sight. In some instances, the decision to strike or not strike has been made by President Obama. This fact inspired news reports of an "Obama kill list." The term was meant to shock, but in a sense, it should provide reassurance. These sorts of killings are extraordinary events. It they are going to happen, especially if there's a risk of harming innocent civilians nearby, it's better to put the decision in the hands of the president—who is politically accountable—than to leave it, say, to a three-star general or the director of the CIA.

The existence of a presidential kill list should also discredit the popular notion that drones are "robots"—autonomous machines—or that the Pentagon is programming them to hunt, find, and kill targets automatically, without human intervention. The idea may be technically feasible (and drones *are* being designed to do everything on autopilot except pull the trigger), but it goes against the U.S. military's command culture. The only thing unmanned about an unmanned aerial vehicle is the vehicle, the drone itself. According to U.S. Air Force figures, each drone flying on a combat air patrol is supported by 43 service members rotating in three shifts, including seven joystick pilots, seven system operators, and five mission coördinators—backed by a 66-person intelligence unit, including 18 intelligence analysts and 34 video crew members. Two well-placed officials also told me of a firm rule that a drone's weapon will not be fired unless the target's presence is confirmed by at least two sources—for instance, spies on the ground *and* signals intelligence or cell-phone intercepts.

The rise of the drone is not a case of technology run amok. It is the result of political calculation and strategic evasion.

This is a crucial point. The rise of the drone is not a case of technology run amok. It is the result of human decision: of political calculation and, too often, strategic evasion. Judging from its expanded use over the past five years, the drone's chief danger is that it makes war too easy—so easy that commanders, including the commander-in-chief, can fool themselves into thinking they're not fighting a war at all.

The drones hover at godlike heights. There's no need to send in troops; even their pilots sit in a trailer on a military base half a world away. In the aftermath of two decade-long wars in Iraq and Afghanistan, where nearly 7,000 Americans have been killed and more than 16,000 severely injured, remote-control warfare has an understandable allure—not just for military commanders and politicians but for all Americans.

An American Weapon, for Now

THE DRONE'S APPEAL HAS NOT BEEN LOST ON THE rest of the world's leaders. Eighty countries now have drones of some sort in their arsenals; 16 of them have drones that can be armed with bombs or missiles. To date, only two countries besides the United States are believed to have killed people with drone strikes: the United Kingdom in Afghanistan, and Israel in Gaza City. For most countries, drone ownership yields few benefits. The drones are short-range, and the nations owning them lack the satellites necessary for real-time video streaming or accurate targeting.

But this is bound to change. Monopolies don't last long in arms competitions, and drones are unlikely to be an exception. An old military adage had it that killing people is easy but killing a person is very hard. That's no longer the case. It's easy for an American official to kill a particular person anywhere on the planet, so long as that person can be found. Someday it will almost certainly be easy for others elsewhere to kill a particular American.

Today the armed drone is an almost uniquely American weapon, and its effect, in strictly military terms, is mixed. It is worth recalling the many times a drone has reportedly killed a "number 3 leader of al-Qaeda." There was always some number 4 leader of al-Qaeda standing by to take his place. It's become a high-tech reprise of the body-count syndrome from the Vietnam War—the illusion that there's a relationship between the number of enemy killed and the proximity to victory.

Drones are weapons of war, sometimes very useful ones. They make it possible to kill someone more easily than ever. But killing someone, even a major enemy combatant, doesn't mean winning, or even getting closer to winning, a war. Depending on how the killing is done, it could push the war's strategic goal further away. T

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A neuroscientist who has anguished over the terrors in her own family's history says people might soon erase the trauma from bad memories by taking a pill—or talking to a therapist—at just the right time.

Repairing Bad Memories

By Stephen S. Hall

It was a Saturday night at the New York Psychoanalytic Institute, and the second-floor auditorium held an odd mix of gray-haired, cerebral Upper East Side types and young, scruffy downtown grad students in black denim. Up on the stage, neuroscientist Daniela Schiller, a riveting figure with her long, straight hair and impossibly erect posture, paused briefly from what she was doing to deliver a mini-lecture about memory.

She explained how recent research, including her own, has shown that memories are not unchanging physical traces in the brain. Instead, they are malleable constructs that may be rebuilt every time they are recalled. The research suggests, she said, that doctors (and psychotherapists) might be able to use this knowledge to help patients block the fearful emotions they experience when recalling a traumatic event, converting chronic sources of debilitating anxiety into benign trips down memory lane.

And then Schiller went back to what she had been doing, which was providing a slamming, rhythmic beat on drums and backup vocals for the Amygdaloids, a rock band com-

Illustrations by Jacob Escobedo


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posed of New York City neuroscientists. During their performance at the institute's second annual "Heavy Mental Variety Show," the band blasted out a selection of its greatest hits, including songs about cognition ("Theory of My Mind"), memory ("A Trace"), and psychopathology ("Brainstorm").

"Just give me a pill," Schiller crooned at one point, during the chorus of a song called "Memory Pill." "Wash away my memories ..."

The irony is that if research by Schiller and others holds up, you may not even need a pill to strip a memory of its power to frighten or oppress you.

Schiller, 40, has been in the vanguard of a dramatic reassessment of how human memory works at the most fundamental level. Her current lab group at Mount Sinai School of Medicine, her former colleagues at New York University, and a growing army of like-minded researchers have marshaled a pile of data to argue that we can alter the emotional impact of a memory by adding new information to it or recalling it in a different context. This hypothesis challenges 100 years of neuroscience and overturns cultural touchstones from Marcel Proust to best-selling memoirs. It changes how we think about the permanence of memory and identity, and it suggests radical nonpharmacological approaches to treating pathologies like post-traumatic stress disorder, other fear-based anxiety disorders, and even addictive behaviors.

In a landmark 2010 paper in *Nature*, Schiller (then a postdoc at New York University) and her NYU colleagues, including Joseph E. LeDoux and Elizabeth A. Phelps, published the results of human experiments indicating that memories are reshaped and rewritten every time we recall an event. And, the research suggested, if mitigating information about a traumatic or unhappy event is introduced within a narrow window of opportunity after its recall—during the few hours it takes for the brain to rebuild the memory in the biological brick and mortar of molecules—the emotional experience of the memory can essentially be rewritten.

"When you affect emotional memory, you don't affect the content," Schiller explains. "You still remember perfectly. You just don't have the emotional memory."

Fear training

The idea that memories are constantly being rewritten is not entirely new. Experimental evidence to this effect dates back at least to the 1960s. But mainstream researchers tended to ignore the findings for decades because they contradicted the prevailing scientific theory about how memory works.

That view began to dominate the science of memory at the beginning of the 20th century. In 1900, two German scientists, Georg Elias Müller and Alfons Pilzecker, conducted a series of human experiments at the University of Göttingen. Their results suggested that memories were fragile at the moment of formation but were strengthened, or consolidated, over time; once consolidated, these memories remained essentially static, permanently stored in the brain like a file in a cabinet from which they could be retrieved when the urge arose.

It took decades of painstaking research for neuroscientists to tease apart a basic mechanism of memory to explain how consolidation occurred at the level of neurons and proteins: an experience entered the neural landscape of the brain through the senses, was initially "encoded" in a central brain apparatus known as the hippocampus, and then migrated—by means of biochemical and electrical signals—to other precincts of the brain for storage. A famous chapter in this story was the case of "H.M.," a young man whose hippocampus was removed during surgery in 1953 to treat debilitating epileptic seizures; although physiologically healthy for the remainder of his life (he died in 2008), H.M. was never again able to create new long-term memories, other than to learn new motor skills.

Subsequent research also made clear that there is no single thing called memory but, rather, different types of memory that achieve different biological purposes using different neural pathways. "Episodic" memory refers to the recollection of specific past events; "procedural" memory refers to the ability to remember specific motor skills like riding a bicycle or throwing a ball; fear memory, a particularly powerful form of emotional memory, refers to the immediate sense of distress that comes from recalling a physically or emotionally dangerous experience. Whatever the memory, however, the theory of consolidation argued that it was an unchanging neural trace of an earlier event, fixed in long-term storage. Whenever you retrieved the memory, whether it was triggered by an unpleasant emotional association or by the seductive taste of a madeleine, you essentially fetched a timeless narrative of an earlier event. Humans, in this view, were the sum total of their fixed memories. As recently as 2000 in *Science*, in a review article titled "Memory—A Century of Consolidation," James L. McGaugh, a leading neuroscientist at the University of California, Irvine, celebrated the consolidation hypothesis for the way that it "still guides" fundamental research into the biological process of long-term memory.

As it turns out, Proust wasn't much of a neuroscientist, and consolidation theory couldn't explain everything about memory. This became apparent during decades of research into what is known as fear training.

Schiller gave me a crash course in fear training one afternoon in her Mount Sinai lab. One of her postdocs, Dorothee Bentz, strapped an electrode onto my right wrist in order to deliver a mild but annoying shock. She also attached sensors

Daniela Schiller

to several fingers on my left hand to record my galvanic skin response, a measure of physiological arousal and fear. Then I watched a series of images—blue and purple cylinders—flash by on a computer screen. It quickly became apparent that the blue cylinders often (but not always) preceded a shock, and my skin conductivity readings reflected what I'd learned. Every time I saw a blue cylinder, I became anxious in anticipation of a shock. The "learning" took no more than a couple of minutes, and Schiller pronounced my little bumps of anticipatory anxiety, charted in real time on a nearby monitor, a classic response of fear training. "It's exactly the same as in the rats," she said.

In the 1960s and 1970s, several research groups used this kind of fear memory in rats to detect cracks in the theory of memory consolidation. In 1968, for example, Donald J. Lewis of Rutgers University led a study showing that you could make the rats lose the fear associated with a memory if you gave them a strong electroconvulsive shock right after they were induced to retrieve that memory; the shock produced an amnesia about the previously learned fear. Giving a shock to animals that had not retrieved the memory, in contrast, did not cause amnesia. In other words, a strong shock timed to occur immediately after a memory was retrieved seemed to have a unique capacity to disrupt the memory itself and allow it to be reconsolidated in a new way. Follow-up work in the 1980s confirmed some of these observations, but they lay so far outside mainstream thinking that they barely received notice.

Moment of silence

At the time, Schiller was oblivious to these developments. A self-described skateboarding "science geek," she grew up in Rishon LeZion, Israel's fourth-largest city, on the coastal plain a few miles southeast of Tel Aviv. She was the youngest of four children of a mother from Morocco and a "culturally Polish" father from Ukraine—"a typical Israeli melting pot," she says. As a tall, fair-skinned teenager with European features, she recalls feeling estranged from other neighborhood kids because she looked so German.

Schiller remembers exactly when her curiosity about the nature of human memory began. She was in the sixth grade, and it was the annual Holocaust Memorial Day in Israel. For a school project, she asked her father about his memories as a Holocaust survivor, and he shrugged off her questions. She was especially puzzled by her father's behavior at 11 A.M., when a simultaneous eruption of sirens throughout Israel signals the start of a national moment of silence. While everyone else in the country stood up to honor the victims of genocide, he stubbornly remained seated at the kitchen table as the sirens blared, drinking his coffee and reading the newspaper.

"The Germans did something to my dad, but I don't know what because he never talks about it," Schiller told a packed audience in 2010 at The Moth, a storytelling event.

During her compulsory service in the Israeli army, she organized scientific and educational conferences, which led to studies in psychology and philosophy at Tel Aviv University; during that same period, she procured a set of drums and formed her own Hebrew rock band, the Rebellion Movement. Schiller went on to

Portrait by Walter Smith

receive a PhD in psychobiology from Tel Aviv University in 2004. That same year, she recalls, she saw the movie *Eternal Sunshine of the Spotless Mind*, in which a young man undergoes treatment with a drug that erases all memories of a former girlfriend and their painful breakup. Schiller heard (mistakenly, it turns out) that the premise of the movie had been based on research conducted by Joe LeDoux, and she eventually applied to his lab for a postdoctoral fellowship.

In science as in memory, timing is everything. Schiller arrived at NYU just in time for the second coming of memory reconsolidation in neuroscience.

Altering the story

The table had been set for Schiller's work on memory modification in 2000, when Karim Nader, a postdoc in LeDoux's lab, suggested an experiment testing the effect of a drug on the formation of fear memories in rats. LeDoux told Nader in no uncertain terms that he thought the idea was a waste of time and money. Nader did the experiment anyway. It ended up getting published in *Nature* and sparked a burst of renewed scientific interest in memory reconsolidation (see "Manipulating Memory," May/June 2009).

The rats had undergone classic fear training—in an unpleasant twist on Pavlovian conditioning, they had learned to associate an auditory tone with an electric shock. But right after the animals retrieved the fearsome memory (the researchers knew they had done so because they froze when they heard the tone), Nader injected a drug that blocked protein synthesis directly into their amygdala, the part of the brain where fear memories are believed to be stored. Surprisingly, that appeared to pave over the fearful association. The rats no longer froze in fear of the shock when they heard the sound cue.

Decades of research had established that long-term memory consolidation requires the synthesis of proteins in the brain's memory pathways, but no one knew that protein synthesis was required after the *retrieval* of a memory as well—which implied that the memory was being consolidated then, too. Nader's experiments also showed that blocking protein synthesis prevented the animals from recalling the fearsome memory only if they received the drug at the right time, shortly after they were reminded of the fearsome event. If Nader waited six hours before giving the drug, it had no effect and the original memory remained intact. This was a big biochemical clue that at least some forms of memories essentially had to be neurally rewritten every time they were recalled.

When Schiller arrived in LeDoux's lab in 2004, she was asked to extend Nader's findings and test the potential of a drug to block fear memories in humans. The drug used in the rodent experiment was much too toxic for human use, but a class of anti-anxiety drugs known as beta-adrenergic antagonists (or, in common parlance, "beta blockers") had potential; among these drugs was propranolol, which had previously been approved by the FDA for the treatment of panic attacks and stage fright. Schiller immediately set out to test the effect of propranolol on memory in humans, but she never actually performed the experiment because of prolonged delays in getting institutional approval for what was then a pioneering form of human experimentation. "It took four years to get approval," she recalls, "and then two months later, they took away the approval again. My entire postdoc was spent waiting for this experiment to be approved." ("It still hasn't been approved!" she adds.)

While waiting for the approval that never came, Schiller began to work on a side project that turned out to be even more interesting. It grew out of an offhand conversation with a colleague about some anomalous data described at meeting of LeDoux's lab: a group of rats "didn't behave as they were supposed to" in a fear experiment, Schiller says.

The data suggested that a fear memory could be disrupted in animals even without the use of a drug that blocked protein synthesis. Schiller used the kernel of this idea to design a set of fear experiments in humans, while Marie-H. Monfils, another member of the lab, simultaneously pursued a parallel line of experimentation in rats. In the human experiments, volunteers were shown a blue square on a computer screen and then given a shock. Once the blue square was associated with an impending shock, the fear memory was in place. Schiller went on to show that if she repeated the sequence that produced the fear memory the following day but broke the association within a narrow window of time—that is, showed the blue square without delivering the shock—this new information was incorporated into the memory.

Here, too, the timing was crucial. If the blue square that wasn't followed by a shock was shown within 10 minutes of the initial memory recall, the human subjects reconsolidated the memory without fear. If it happened six hours later, the initial fear memory persisted. Put another way, intervening during the brief window when the brain was rewriting its memory offered a chance to revise the initial memory itself while diminishing the emotion (fear) that came with it. By mastering the timing, the NYU group had essentially created a scenario in which humans could rewrite a fearsome memory and give it an unfrightening ending. And this new ending was robust: when Schiller and her colleagues called their subjects back into the lab a year later, they were able to show that the fear associated with the memory was still blocked.

The study, published in *Nature* in 2010, made clear that reconsolidation of memory didn't occur only in rats.

The safest memories

As a scientific idea, memory reconsolidation seems to be here to stay. Schiller notes that when she first started going to the massive annual meeting of the Society for Neuroscience a decade ago, she was lucky to see a single poster about reconsolidation theory. "Now," she says, "it's like entire alleys in the exhibition hall."

More important, Schiller's work has been quickly replicated and extended. Thomas Agren and colleagues at Uppsala University in Sweden confirmed last year that disrupting reconsolidation when humans reactivated a fear memory effectively abolished its fearsome effect; the group also showed through brain imaging in these volunteers that the amygdala was the locus of the changed memory. Yan-Xue Xue of Peking University in Beijing and colleagues reported last year that they had used nonpharmacological memory manipulation to help heroin addicts rewrite their association of environmental cues with a craving for the drug; the researchers said the effect lasted at least half a year, which was the length of the study.

Since moving uptown from NYU to Mount Sinai in 2010, Schiller has embarked on a new set of experiments exploring the clinical potential of memory reconsolidation. That in part explains why she shares her ninth-floor office with a tarantula, which sits in a cage under her desk. Called Web 2.0 (the name was bestowed by a member of Schiller's research group, a former writer on *Saturday Night Live*), the spider plays a role in ongoing experiments to block arachnophobia (fear of spiders) in humans without any drugs.

"We are looking at the neural mechanisms of reconsolidation," she says. Those mechanisms—at both the synaptic level and the level of the whole brain—are fairly well understood in animals but not so easy to study in humans. "There are basically only two things you can do," she continues. "One is to do pharmacological studies, and the other is to look at brain function in an MRI as people update memories." They hope to publish findings on both fronts in the near future.

The reconstitution of memory has enormous therapeutic potential. Administering drugs like propranolol within hours of a traumatic experience might modify or minimize the long-term emotional impact of the memory. But if that's not possible, the memory might be modified later, when the experience is recalled in a safe, unthreatening context. Roger Pitman of Harvard Medical School, Karim Nader (now at McGill University), and their colleagues have reported that giving propranolol to people as they recall a traumatic experience can attenuate the emotional impact of the memory, giving hope for treatment of anxiety disorders like PTSD. Schiller views this as very promising. "If you miss intervening a few hours after the event," she says, "you still have other opportunities to intervene."

In some ways, the potential cultural impact and personal implications of reconsolidation are even more staggering. To put it in an extreme way, if we are all rewriting our memories every time we recall an event, the memory exists not as a file in our brain but only as the most recent rewrite of a scenario. Every memoir is fabricated, and the past is nothing more than our last retelling of it. Archival memory data is mixed with whatever new information helps shape the way we think—and feel—about it. "My conclusion," says Schiller, "is that memory is what you are now. Not in pictures, not in recordings. Your memory is who you are now."

In Schiller's view, then, the secret to preserving a memory doesn't lie in protein synthesis in the synapses or the shuttling of neural traffic from the hippocampus to the exurbs of the brain. Rather, she believes, memory is best preserved in the form of a story that collects, distills, and fixes both the physical and the emotional details of an event. "The only way to freeze a memory," she says, "is to put it in a story." Which ultimately brings us back to her father.

When she first told the story about Holocaust Memorial Day at The Moth in 2010, Schiller speculated that the sirens functioned as what psychologists call a "conditioned stimulus"—a sensory cue, very much in the Pavlovian tradition, that triggered a painful memory. And in light of her work on reconsolidated memory, she began to think that by sitting at the kitchen table sipping his coffee, her father was rewriting his painful memories by associating them with a pleasant activity.

But even her personal story about memory, like memory itself, has begun to update itself. Last year, for the first time, Schiller's father briefly spoke about his teenage years—about the selflessness of his mother and uncle in a time of great deprivation, and most of all about his close relationship with his younger sister, who perished in the Holocaust. Schiller now suspects that her father's reluctance to recall those traumatic events is a way of protecting and preserving memories so beautiful that he wants never to rewrite them and risk losing their power.

Since then, they've reverted to their usual three-word conversations about the Holocaust. "Because they are so precious, these are memories you don't want to change," she says. "The safest memories are those you never remember." T

Stephen S. Hall's latest book is Wisdom: From Philosophy to Neuroscience *(Vintage). His last story for* MIT Technology Review *was "The Dementia Plague" in November/December 2012.*

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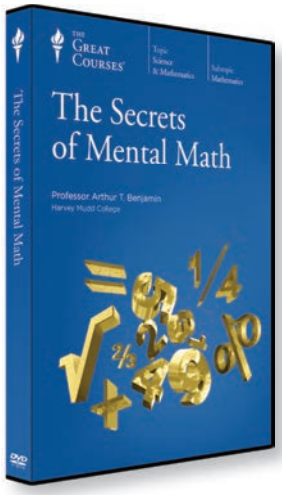

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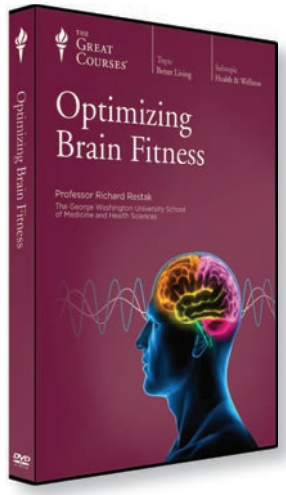

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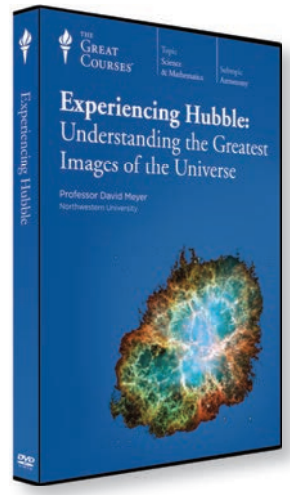

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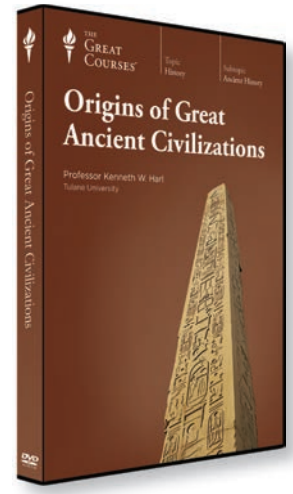

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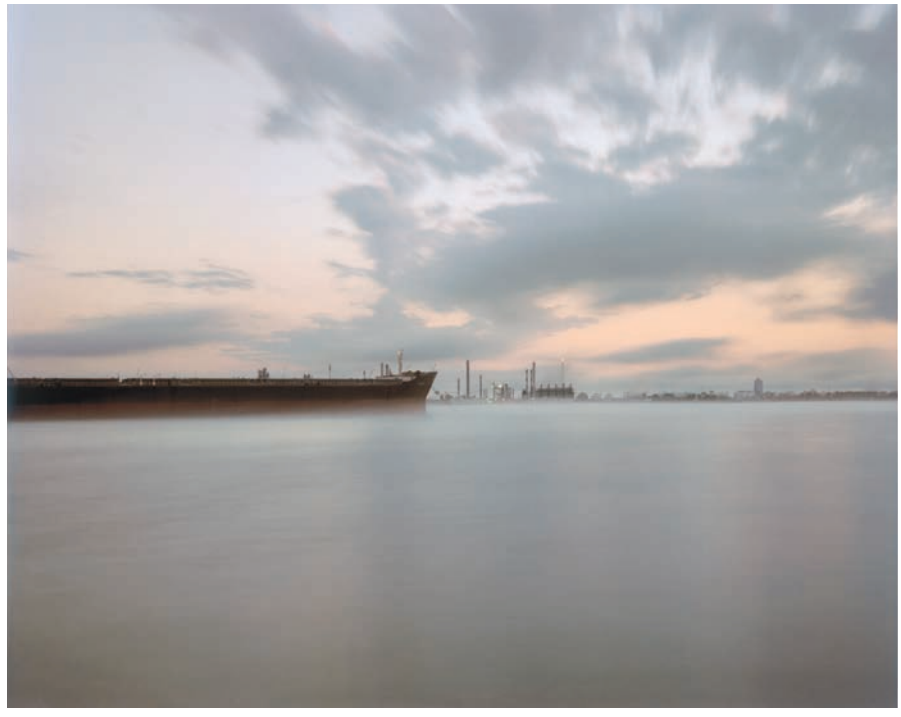

America's Petrochemical Landscape

Photographs by Richard Misrach

In 1998, the landscape photographer Richard Misrach roamed Louisiana to document a legacy of its petrochemical industry. In a series of stark photographs, he captured how the infrastructure of oil, gas, and chemical companies dominates the environment, running through waterways and open spaces and looming over neighborhoods. The photos seen here, along with others by Misrach, formed the basis of a 2012 book, *Petrochemical America*, in which the landscape architect Kate Orff also mapped the environmental damage wrought by the industry. Misrach's photos serve as a reminder of how widely the petrochemical business encroaches, well beyond the sites where oil and gas are pulled from the earth.

OPPOSITE:
Tanker on Mississippi River near Bonnet Carré Spillway Norco, Louisiana, 1998

ABOVE:
Shell Chemicals refinery Norco, Louisiana, 1998

—

Hydrocarbons from the huge refinery frequently combine with moisture in the air to produce natural-looking clouds nicknamed “Norco cumulus.”

Orion refinery, Good Hope, Louisiana, 1998

Swamp and pipeline, Geismar, Louisiana, 1998

OPPOSITE, TOP:
Trailer home and natural gas tanks
Good Hope Street, Norco, Louisiana, 1998

—

The town of Sellers was renamed Norco—an acronym for the New Orleans Refining Company—in the 1930s. After decades of complaints and lawsuits, Shell relocated most of the town's residents in 2002.

OPPOSITE, BOTTOM:
Playground and Shell refinery
Norco, Louisiana, 1998

—

Misrach says the basketball court was all that remained of an elementary school that burned down in 1968, on the eve of its desegregation.

ABOVE:
View of Exxon refinery, State Capitol
Baton Rouge, Louisiana, 1998

MIT Technology Review

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A BUSINESS REPORT ON

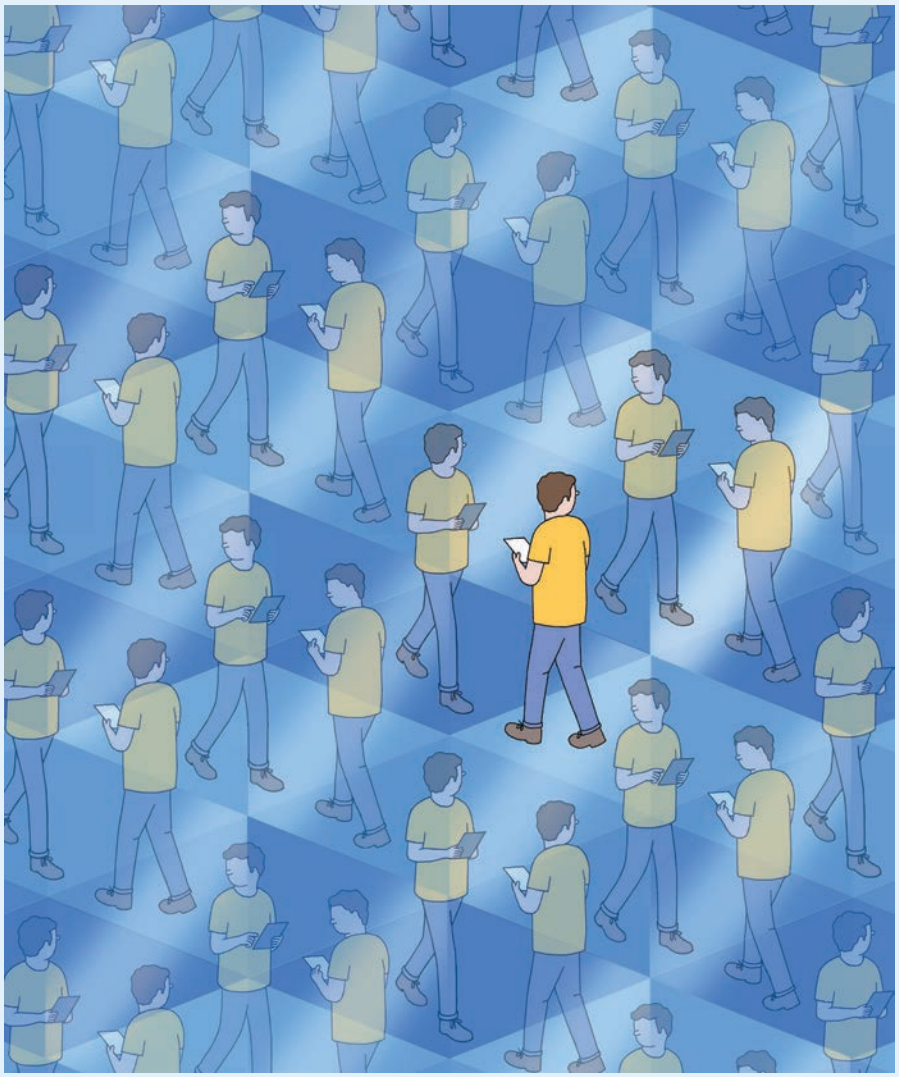
Big Data Gets Personal

Big data and personal data are converging to shape the Internet's most surprising consumer products. They'll predict your needs and store your memories—if you let them.

CONTENTS

Read all 12 stories in this report at technologyreview.com/business

Additional stories include "Augmenting Social Reality in the Workplace," "The Dictatorship of Data," "Marketing to the Big Data Inside Us," "Intel Fuels a Rebellion Around Your Data," and more.



LAURIE ROLLITT

The Big Question

The Data Made Me Do It

The next frontier for big data is the individual.

● Would you trade your personal data for a peek into the future? Andreas Weigend did.

Weigend, the former chief scientist of Amazon.com who now directs Stanford University's Social Data Lab, told me a story about awakening at dawn to catch a flight from Shanghai. That's when an app he'd begun using, Google Now, told him his flight was delayed.

The software scours a person's Gmail and calendar, as well as databases like maps and flight schedules. It had spotted the glitch in his travel plans and sent the warning that he shouldn't rush. When Weigend finally boarded, everyone else on the plane had been waiting for hours for a spare part to arrive.

For Weigend, a consultant and lecturer on consumer behavior, such episodes demonstrate "the power of a society based on 10 times as much data." →

If the last century was marked by the ability to observe the interactions of physical matter—think of technologies like x-ray and radar—this century, he says, is going to be defined by the ability to observe people through the data they share.

So-called anticipatory systems such as Google Now represent one example of what could result. We're already seeing the transformations that big data is causing in advertising and other situations where millions of people's activity can be measured at a time. Now data science is looking at how it can help individuals. Timely updates on a United Airways flight may be among the tamer applications. Think instead of statistical models that tell you what job to take, or alert you even before you feel ill that you may have the flu.

Driving this trend is a swelling amount of personal data available to computers. The amount of digital data being created globally is doubling every two years, and the majority of it is generated by consumers, in the form of movie downloads, VoIP calls, e-mails, cell-phone location readings, and so on, according to the consultancy IDC. Yet only about 0.5 percent of that data is ever analyzed.

"There is so much more data out there that you can afford to tailor it to the individual," says Patrick Wolfe, a statistician who studies social networks at University College, London. "Statistically, strength comes from pooling people together, but then the icing on the cake is when you individualize the findings."

99.5%
Percentage of newly created digital data that's never analyzed

For the data refineries of Silicon Valley, like Google, Facebook, and LinkedIn, the merger of big data and personal data has been a goal for some time. It creates tools advertisers can use, and it makes products that are particularly "sticky," too. After all, what's more interesting than yourself? Facebook suggests who your friends might be. Google Now gets better the more data you give it.

Exposing more personal data seems inevitable. With the huge jump in sales of smartphones packed with accelerometers, cameras, and GPS, "people have become instrumented to collect and transmit personal data," says Weigend. And that may be just the start. Already a fringe community of technophiles in what's known as the quantified-self movement have been equipping their bodies with sensors, pedometers, even implanted glucose monitors.

One technophile we feature in this report is Stephen Wolfram, the creator of the search engine Wolfram Alpha, who has for years engaged in a massive self-tracking project, cataloguing e-mails, keystrokes, even his physical movements. Wolfram is interested in predictive apps but also in the insights that large data sets can have on personal behavior, something he calls "personal analytics." Wolfram's idea is that just as his search engine tries to organize all facts about the world, "what you have to do in personal analytics is try to accumulate the knowledge of a person's life."

The holdup, says Wolfram, is that some of the most useful data isn't being captured, at least not in a way that's easily accessible. Part of the problem is technical, a lack of integration. But much data is warehoused by private companies like Facebook, Apple, and Fitbit, maker of a popular pedometer. Now, as the value of personal data becomes more apparent, fights are brewing. California legislators this year introduced a "Right to Know" bill that would require companies to reveal to individuals the "personal information" they store—in other words, a digital copy of every location trace and sighting of their IP address.

The bill is a part of a social movement that is demanding privacy and accountability but also a different economic arrangement between the people who supply the data and those who apply it. People want more of the direct benefits of big data, and this month's *MIT Technology Review* Business Report tracks the technology, apps, and business ideas with which industry is responding.

—Antonio Regalado

Emerged Technologies

Has Big Data Made Anonymity Impossible?

As the amount of data expands exponentially, nearly all of it carries someone's digital fingerprints.

● In 1995, the European Union introduced privacy legislation that defined "personal data" as any information that could identify a person, directly or indirectly. The legislators were apparently thinking of things like documents with an identification number, and they wanted them protected just as if they carried your name.

Today, that definition encompasses far more information than those European legislators could have imagined—more than all the bits and bytes in the entire world when they wrote their law 18 years ago.

Here's what happened. First, the amount of data created each year has grown exponentially: it reached 2.8 zettabytes in 2012, a number that's as gigantic as it sounds, and will double again by 2015, according to the consultancy IDC. Of that, about three-quarters is generated by individuals as they create and move digital files. A typical American office worker produces 1.8 million megabytes of data each year. That is about 5,000 megabytes a day, including downloaded movies, Word files, e-mail, and the bits generated by computers as that information is moved across mobile networks or the Internet.

Much of this data is invisible to people and seems impersonal. But it's not. What modern data science is finding is that nearly any type of data can be used, much like a fingerprint, to identify the person who created it: your choice of movies on Netflix, the location signals emitted by your cell phone, even your pattern of walking as recorded by a surveillance camera. In effect, the more

data there is, the less any of it can be said to be private, since the richness of that data makes pinpointing people "algorithmically possible," says Princeton University computer scientist Arvind Narayanan.

We're well down this path already. The information we thought of as personal data in the past—our name, address, or credit card records—is already bought and sold by data brokers like Acxiom, a company that holds an average of 1,500 pieces of information on more than 500 million consumers. This is data that people put into the public domain on a survey form or when they signed up for services such as TiVo.

Acxiom uses information about the make and year of your car, your income and investments, and your age, education, and zip code to place you in one of 70 different "PersonicX" clusters, which are "summarized indicators of lifestyle, interests, and activities." Did you just finalize a divorce or become an empty nester? Such "life events," which move people from one consumer class to another, are of key interest to Acxiom and its advertising clients. The company says it can analyze its data to predict 3,000 different propensities, such as how a person may respond to one brand over another.

Yet these data brokers today are considered somewhat old-fashioned compared with Internet companies like Facebook, which have automated the collection of personal information so it can be done in real time. According to its financial filings at the time of its IPO, Facebook stores around 111 megabytes of photos and videos for each of its users, who now number more than a billion. That's 100 petabytes of personal information right there. In some European legal cases, plaintiffs have learned that Facebook's records of their interactions with the site—including text messages, things they "liked," and addresses of computers they used—run to 800 printed pages, adding up to another few megabytes per user.

In a step that's worrisome to digital-privacy advocates, offline and online data sets are now being connected to help marketers target advertisements more precisely. In February, Facebook announced a deal with Acxiom and other data brokers to merge their data, linking real-world activities to those on the Web. At a March investor meeting, Acxiom's chief science officer claimed that its data could now be linked to 90 percent of U.S. social profiles.

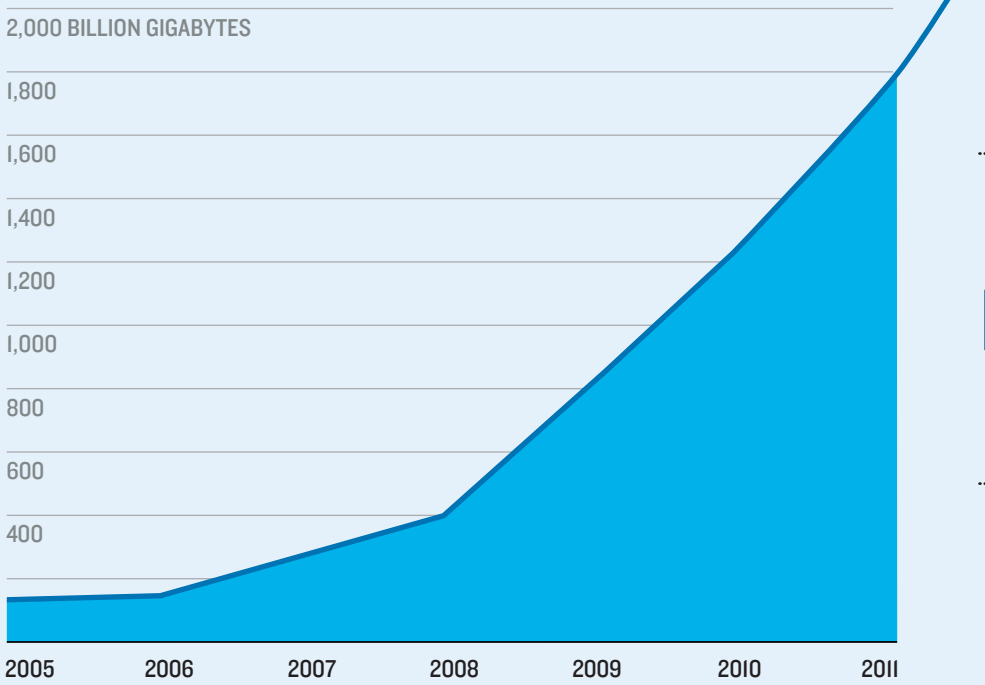
Such data sets are often portrayed as having been "anonymized" in some way, but the more data they involve, the less likely that is to be actually true. Mobile-phone companies, for instance, record users' loca- →

65 billion
Location-tagged payments made in the U.S. annually

154 billion
E-mails sent per day

87%
U.S. adults whose location is known via their mobile phone

Digital Information Created Each Year, Globally



2,000%
Expected increase in global data by 2020

111 Megabytes
Video and photos stored by Facebook, per user

75%
Percentage of all digital data created by consumers

SOURCES: IDC, RADICATI GROUP, FACEBOOK, TR RESEARCH, PEW INTERNET

tions, strip out the phone numbers, and sell aggregate data sets to merchants or others interested in people's movements. MIT researchers Yves-Alexandre de Montjoye and César A. Hidalgo have shown that even when such location data is anonymous, just four different data points about a phone's position can usually link the phone to a unique person.

The greater the amount of personal data that becomes available, the more informative the data gets. In fact, with enough data, it's even possible to discover information about a person's future. Last year Adam Sadilek, a University of Rochester researcher, and John Krumm, an engineer at Microsoft's research lab, showed they could predict a person's approximate location up to 80 weeks into the future, at an accuracy of above 80 percent. To get there, the pair mined what they described as a "massive data set" collecting 32,000 days of GPS readings taken from 307 people and 396 vehicles.

Then they imagined the commercial applications, like ads that say "Need a haircut? In four days, you will be within 100 meters of a salon that will have a $5 special at that time." Sadilek and Krumm called their system "Far Out." That's a pretty good description of where personal data is taking us. *—Patrick Tucker*

Emerged Technologies

Predictive Apps Mine Your Life

In a break from traditional software, new apps offer information proactively.

● A new type of mobile app is departing from a long-standing practice in computing. Typically, computers have just dumbly waited for their human operators to ask for help. But now applications based on machine learning software can speak up with timely information even without being directly asked for it. They might automatically pull up a boarding pass for your flight just as you arrive at the airport, or tell you that current traffic conditions require you to leave for your next meeting within 10 minutes.

The highest-profile of these apps is Google Now, which is a feature of the latest version of the Android mobile operating system and was recently added to the Google search app for the iPhone. Google Now is trained to predict when a person is about to take certain actions and offer help accordingly. It can also learn about an individual to fine-tune the assistance it offers.

Google Now's algorithms use the data in a person's Google e-mail and calendar accounts and Web searches. The app learns where you live and work and when you commute so that it can offer a virtual index card showing traffic or transit information. Other cards offer boarding passes and other handy information at appropriate times.

Bill Ferrell, founder and CEO of Osito, a company with an iPhone app that offers similar functions, calls this idea "predictive intelligence." Osito's system foretells a person's actions and needs from location, e-mail, and calendar data and uses those predictions to go beyond offering just advice. It also presents ways for a person to take action. A flight reminder will include a button to summon a cab, for example.

Now that the first generation of this type of app has been well received, engineers at Google, Osito, and elsewhere seek to wring more insights from the data they collect about their users. Osito's engineers are working to learn more from a person's past location traces to refine predictions of future activity, says Ferrell. Google Now recently began showing the weather in places it believes you're headed to soon. It can also notify you of nearby properties for

Anticipatory Systems Guess Your Next Move
Smartphone apps that mine personal data in order to anticipate a person's needs

NAME	Cue	Google Now	Osito	Tempo AI	Dark Sky
RAISED	$4.7 million	N/a	$1.1 million	Incubated at SRI International	$39,376
FOUNDED BY	Y Combinator graduates Daniel Gross and Robby Walker	An internal Google team	Bill Ferrell, a former Google developer	Raj Singh, Corey Hulen, and Thierry Donneau-Golencer	Jack Turner and Adam Grossman
PREDICTIONS	Summarizes a person's day based on information scavenged from calendar, e-mail, and documents	Directions, traffic, and weather based on a person's location and calendar	Handles transactions like checking in for a flight or calling a cab after you land at the airport	Directions to appointments. Also sends messages if you're running late	Provides minute-by-minute weather forecasts for user's exact location

SOURCES: CUE, GOOGLE NOW, OSITO, TEMPO AI, DARK SKY

sale if you have recently done a Web search suggesting you're looking for a new home.

Machine learning experts at Grokr, a predictive app for the iPhone, have found they can divine the ethnicity, gender, and age of their users to a high degree of accuracy, says CEO Srivats Sampath. "That can help us predict places you might like to go better," he says. The information will be used to fine-tune the recommendations Grokr offers for restaurants and music events.

These apps benefit from improved data-mining techniques, but they're also succeeding partly because of how they are presented to users. They are not cast as artificial butlers, a staple of science fiction that Apple tried to mimic with the voice-operated app Siri in 2010. Instead, apps like Google Now are intentionally made without personality and don't pretend to be people.

That plays to the strengths of today's artificial-intelligence technology, says Mike Volpi, a partner with venture capital firm Index Ventures, which invested in a predictive iPhone app called Donna. "An assistant probably is one of the most tough use cases, because you set up the expectation it will be human-level," says Volpi.

Apple's assistant has not become a core part of many iPhone users' lives, he says, because software cannot recognize speech accurately enough. Apple may have exacerbated this problem by giving its app the capacity for witty repartee and running TV ads in which Siri appears to act with almost humanlike intelligence.

Hilary Mason, chief data scientist at the Web company Bit.ly, has mixed reviews for Google Now. She finds that it's often serving up unnecessary information: for example, she says, she doesn't need to be told that she is near a Staples office supply store, which is true in many parts of Manhattan, or be given a bus schedule every time she passes a bus stop. "It's not quite tuned to what matters to me," she says.

But still, it represents a milestone in computing, she adds: "Google Now is kind of a sucky product, but I use it anyway. It's important because it's the first time Google has taken all they know about us to make a product that makes our lives better."

—Tom Simonite

Case Studies

Data Won the Election. Can It Save the World?

Data scientist Rayid Ghani helped persuade voters to reëlect President Obama. Now he's using big data to create a groundswell of social good.

● As chief scientist for President Obama's reëlection effort, Rayid Ghani helped revolutionize the use of data in politics. During the final 18 months of the campaign, a sprawling team of data and software experts sifted, collated, and combined dozens of pieces of information on each registered U.S. voter to discover patterns that let them target fund-raising appeals and ads to those most likely to respond.

Now, with Obama again ensconced in the Oval Office, some veterans of the data squad are applying lessons from the campaign to tackle social issues such as education or health care. Edgeflip, a startup Ghani founded in January with two other campaign members, plans to turn the ad hoc data analysis tools developed for Obama for America into software that can make nonprofits more effective at raising money and recruiting volunteers.

Ghani isn't the only one thinking along these lines. In Chicago, Ghani's hometown and the site of Obama for America headquarters, some campaign members are helping the city make records of utility usage and crime statistics available so that developers can build apps that attempt to improve life there.

It's all part of a bigger idea to "engineer social systems" by scanning the numerical exhaust from mundane activities—phone calls, online searches—for patterns that might bear on everything from traffic snarls to human trafficking. Among those pursuing such humanitarian goals are startups like DataKind as well as large companies like IBM, which is redrawing bus routes in Ivory Coast, and Google, with its flu-tracking software.

Ghani, 35, always had an interest in social causes, like tutoring disadvantaged kids. But he developed his data-mining savvy during 10 years as director of analytics at Accenture, helping retail chains forecast sales, creating models of consumer behavior, and writing papers with titles like "Data Mining for Business Applications."

Before joining the Obama campaign in July 2011, Ghani wasn't even sure his expertise in machine learning or predicting online prices could have an impact on a social cause. But the campaign's success in applying such methods on the fly to sway voters is now seen as having been potentially decisive in the election's outcome. "I realized two things," says Ghani. "It's doable at the massive scale of the campaign, and that means it's doable in the context of other problems."

"I can imagine policies being designed a lot more collaboratively. I don't know if the politicians are ready to deal with it."

—Rayid Ghani

At Obama for America, Ghani built statistical models that assessed each voter along five axes: support for the president, susceptibility to being persuaded to support the president, and the likelihood of donating money, of volunteering, and of actually casting a vote. These models allowed the campaign to target door knocks, phone calls, TV spots, and online ads to where they were most likely to benefit Obama.

One of the most important ideas Ghani developed during the campaign, dubbed "targeted sharing," now forms the →

basis of Edgeflip's first product. It's a Facebook app that prompts people to share information from a nonprofit, but only with those friends predicted to respond favorably. That's a big change from the usual scattershot approach of posting pleas for money or help and hoping they'll reach the right people.

As Obama's Facebook app did, Ghani says, Edgeflip will ask people who share a post to provide access to their list of friends. This will pull in not only friends' names but personal details, like ages, that can feed models of who is most likely to help.

Say a hurricane strikes the southeastern United States and the Red Cross needs clean-up workers. The app would ask Facebook users to share the Red Cross message, but only with friends who live in the storm zone, are young and likely to do manual labor, and have previously shown interest in content shared by that user. But if the same person shared a donation appeal, he or she would be prompted to pass it along to friends who are older, live farther away, and have donated money in the past.

Michael Slaby, who led Obama's technology team and who hired Ghani, sees great promise in the technique. "It's one of the most compelling innovations to come out of the campaign," he says. "It has the potential to make online activism much more efficient and effective."

For instance, Ghani has been working with Fidel Vargas, CEO of the Hispanic Scholarship Fund, to increase that organization's analytical savvy. Vargas thinks social data could predict which scholarship recipients are most likely to contribute to the fund after they graduate. "Then you'd be able to give away scholarships to qualified students who would have a higher probability of giving back," he says. "Everyone would be much better off."

Ghani sees a far bigger role for technology in the social sphere. He imagines online petitions that act like open-source software, getting passed around and improved. "I can imagine policies being designed a lot more collaboratively," he says. "I don't know if the politicians are ready to deal with it." He also thinks there's a huge amount of untapped information out there about childhood obesity, gang membership, and infant mortality, all ready for big data's touch.

But one thing stands in the way of this vision: a lack of data scientists interested in applying their skills to social problems. This summer, Ghani will be teaching at a fellowship program he developed for the University of Chicago, called Data Science for Social Good, which will put roughly 40 students to work on problems facing nonprofits and governments.

"A lot of the people who have the skills to do this kind of work end up working for Facebook, Google, or the latest online ad network," he says. "I want to show them that the same kind of data is available here, and the impact is bigger." —*Ted Greenwald*

Case Studies

Logging Life with a Lapel Camera

A startup believes people will want a photographic record of their lives, taken at 30-second intervals.

● "We want to provide people with a perfect photographic memory," says Martin Källström, CEO of Memoto. His startup, based in Linköping, Sweden, is creating a tiny clip-on camera that takes a picture every 30 seconds, capturing whatever you are looking at, and then applies algorithms to the resulting mountain of images to find the most interesting ones.

Just 36 by 36 by 9 millimeters, the inconspicuous plastic camera has a lot crammed inside. The most important component is a five-megapixel image sensor originally designed for mobile phones. An ARM 9 processor running Linux powers a program that wakes the device twice a minute; takes a picture and a reading from the GPS sensor, accelerometer, and magnetometer; and promptly puts the device back to sleep.

Later, a user can transfer the pictures to a computer or upload them to Memoto's cloud storage service. The pictures are then fed through an image-processing algorithm that starts to sort out the events in your day. The images are clustered by their predominant colors, and then "we get a diagram of how varied the colors are over the day," says Källström.

That processing turns your photos into "moments"—between 30 and 35 things that have happened during your day, displayed as stacks of photos in a smartphone app or on the Web. Hours in front of a computer add up to one moment, a quick coffee break to another. Each is represented by a single sharp, colorful frame—if possible, one with people in it. "It allows you, in the app, to see the good parts of your day with the boring parts hidden," says Källström.

It's this clever filtering system, Källström believes, that makes the Memoto more than just a camera. He calls it a "life logging" device that will help people remember what they've seen and experienced, or even keep a record for their descendants. "I'd like to be able to put in my will what parts of my life log are going to be available for people that come after me," says Källström. "I've always been fascinated by ways to effortlessly document life."

Källström, a 37-year-old software developer, came up with the Memoto concept in 2011 and began working on it full time the next year with partner Oskar Kalmaru and product designer Björn Wesén. Last fall, the team raised $550,189 from the public on the crowd-funding site Kickstarter, where they promised a camera to anyone who paid $279 up front.

That was far more than the $50,000 they had expected to raise. "We realized that we were going to have to build more cameras," says Källström, with typical Swedish understatement. His company now employs 17 people and he says that despite some unexpected delays in developing and producing the cameras, he expects

Memoto's clip-on camera has eight gigabytes of memory, enough to store four days' worth of photos.

COURTESY OF MEMOTO

Life Loggers

Devices and apps people are using to record aspects of their lives


NAME	AliveCor ECG	Nike+ FuelBand	Foursquare	RunKeeper	Google Glass
COST	$199	$149	Free	Free	$1,500
YEAR INTRODUCED	2013	2012	2009	2008	2013
USERS	not announced	500,000	30 million	18 million	not announced
SPECIALITY	A snap-on electrode that converts an iPhone into an electrocardiogram monitor	A digital bracelet that records physical activity, such as walking and running	An app that tracks a user's location, offering prizes and points for checking in at stores	An app that uses a smartphone's GPS to record a runner's speed and distance covered	A wearable computer that captures photos and videos

SOURCES: ALIVECOR, NIKE, FOURSQUARE, FITNESSKEEPER, GOOGLE

the first 5,000 to arrive later this year from Taiwan, where they are being assembled.

Life logging is quickly becoming a significant business as consumers embrace wearable self-tracking devices such as Nike's FuelBand, a bracelet that measures a person's movements and estimates calories burned. Sharing photos on services like Instagram or Facebook can also be considered a kind of life logging. "It's already mainstream," Källström says.

Many large technology companies are considering how to use wearable devices to collect even more personal data. Google, for instance, is now testing a head-mounted computer that can shoot video.

Recording devices that take photos, like Memoto, are going to challenge social norms and raise new privacy questions. When does recording your own life intrude on someone else's?

Stephen Wolfram, creator of the software Mathematica, has been testing an early Memoto prototype since March and says, "It's still a little bit socially weird." He adds, "I'm not completely sure what to do with the data, and it does generate a lot of data." During one day, the camera can snap 2,000 photos and generate about two gigabytes' worth of files (its flash memory has room for eight gigabytes). Wolfram says that while flipping back through the pictures, he's been able to read name tags of people at conferences whose names he'd forgotten. "I can see all kinds of stuff I didn't notice when I was actually there," he says.

Memoto is designed to automatically stop snapping pictures if it's taken off and placed on a flat surface, or put in a dark place like a pocket. Källström admits there are certain times when it's probably best to leave it at home. "Technology forces us to make new kinds of ethical judgments," he says.

The company's business model is to sell the devices and charge about $8 per month for online storage of people's photos. "It's a lot like a mirror in your bathroom, perhaps," says Källström. "You look into it in the morning, and you know a little bit more about yourself." —*Duncan Geere*

Leaders

Q&A: Stephen Wolfram on Personal Analytics

The creator of the Wolfram Alpha search engine explains why he thinks your life should be measured and analyzed.

● Don't be surprised if Stephen Wolfram, the renowned complexity theorist, software company CEO, and night owl, wants to schedule a work call with you at 9 P.M. After a decade of logging every phone call he makes and keystroke he types, Wolfram knows exactly the probability he'll be on the phone with someone at that time: 39 percent. →

Wolfram, a British-born physicist, is the creator of the software Mathematica and of Wolfram Alpha, the nerdy "computational knowledge engine" that can tell you the distance to the moon right now, in units including light-seconds.

Now Wolfram wants to apply similar techniques to people's personal data, an idea he calls "personal analytics." He started with himself. In a blog post last year, Wolfram analyzed a detailed record of his life stretching back three decades, including hundreds of thousands of e-mails and 10 years of computer keystrokes.

Last year, his company released its first consumer product in this vein, Personal Analytics for Facebook. In under a minute, the software generates a detailed study of a person's relationships and behavior on the site. It looks like a dashboard for your life, which Wolfram says is exactly the point. In a phone call that was recorded and whose start and stop times were entered into Wolfram's life log, he discussed why personal analytics will make people more efficient at work and in their personal lives.

"You're seeing the story of people's lives played out on the level of data."

—Stephen Wolfram

What do you record about yourself?
E-mails, documents, and normally, if I was in front of my computer, it would be recording keystrokes. I have a motion sensor for the room that records when I pace up and down. Also a pedometer, and I am trying to get an eye-tracking system set up. Oh, and I've been wearing a sensor to measure my posture.

Do you think that you're the most quantified person on the planet?
I couldn't imagine that that was the case until maybe a year ago, when I collected a bunch of this data and wrote a blog post on it. I was expecting that there would be people who would come forward and say, "Gosh, I've got way more than you." But nobody's come forward. I think by default that may mean I'm it, so to speak.

You coined this term "personal analytics." What does it mean?
There's organizational analytics, which is looking at an organization and trying to understand what the data says about its operation. Personal analytics is what you can figure out applying analytics to the person, to understand the operation of the person.

Why are you analyzing Facebook data?
We are trying to feel out the market for personal analytics. Most people are not recording all their keystrokes like I am. But the one thing they are doing is leaving lots of digital trails, including on Facebook, and that is one of the pieces we've been experimenting with.

We've accumulated a lot of Facebook data—you're seeing the story of people's lives played out on the level of data. You can see relationship status as a function of age, or the evolution of the clustering of friends at different ages. It's fascinating to see how all this stuff is just right there in the data.

What's the connection to the search engine you built?
Right now Wolfram Alpha is strong on public knowledge: accumulating and searching the knowledge of the civilization. But what you have to do in personal analytics is try to accumulate the knowledge of a person's life. Then the two can actually be integrated, and I'll give a kind of silly example. You might ask: "Who do I know that can go out into their backyard and go and look at the night sky right now?" For that you have to be able to compute who is in nighttime, who doesn't have cloudy weather, and things like this. And we can compute all that stuff.

What do you see as the big applications in personal analytics?
Augmented memory is going to be very important. I've been spoiled because for years I've had the ability to search my e-mail and all my other records. I've been the CEO of the same company for 25 years and so I never changed jobs and lost my data. That's something that I think people will just come to expect. Pure memory augmentation is probably the first step.

The next is preëmptive information delivery. That means knowing enough about people's history to know what they're going to care about. Imagine someone is reading a newspaper article, and we know there is a person mentioned in it that they went to high school with, and so we can flag it. I think that's the sort of thing it's possible to dramatically automate and make more efficient.

Then there will be a certain segment of the population that will be into the self-improvement side of things, using analytics to learn about ourselves. Because when a pattern is explicit, we can decide, "Do we like that behavior, do we not?" Very early on, back in the 1990s, when I first analyzed my e-mail archive, I learned that a lot of e-mail threads at my company would, by a certain time of day, just resolve themselves. That was useful to know, because if I jumped in too early I was just wasting my time.

Are you commercializing these ideas?
The personal analytics of Facebook for Wolfram Alpha is a deployed project, and there will be more of those in the personal-analytics space. We think we can do terrific things, but you have to be able to get to the data. That has been the holdup. The data isn't readily available. Recently we've been working with different companies to try and make sure we can connect their sensors to kind of a generic analytics platform, to take people's data, move it to the cloud, and do analytics on it.

How much better can people become with some data feedback?
I think it will be fairly dramatic. It's like asking how much more money can you make if you track your portfolio rather than just vaguely remembering what investments you made.

—Antonio Regalado

COURTESY OF WOLFRAM ALPHA

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Home Truths

Facebook Home, a new interface for smartphones, is weird, inutile, and at odds with how the world uses computers.

By Paul Ford

When the iPhone was new, Steve Jobs showed one to Alan Kay and asked him if it was "good enough to criticize." Kay, a computing pioneer, had been a hero to Apple's founder: in 1972, when much of the world was still using magnetic tape, he had proposed to his colleagues at Xerox's Palo Alto Research Center a small, portable, and, above all, *personal* computer called the Dynabook. Apple borrowed slavishly from Kay's vision. Over a quarter-century later, Kay told Jobs that the iPhone *could be* worth criticizing—but only if Apple enlarged the screen to the size of a 5-by-8-inch Moleskine notebook.

Facebook Home on the HTC First phone

Kay's 1972 proposal specified the properties of screen, processor, and memory, but the model of computing it described was as much moral as technical: a world of software "objects" that could be directly manipulated by the machine's users, who might be children. This was four years after Douglas Engelbart's demo of NLS (oNLine System), which introduced hypertext, the mouse, and videoconferencing, and two years before Ted Nelson published *Computer Lib/Dream Machines*, a sprawling manifesto of personal liberation through hypertext. All were part of a Palo Alto tradition that believed the computer should be (in Jobs's words) a "bicycle for our minds."

The Android operating system is also part of that tradition—mostly because it borrows the iPhone's conventions, but also because of its parentage at Google, a company whose mission is to "organize the world's information and make it universally accessible and useful." Both Apple and Google sell their users a kind of superhumanism made possible by trillions of processor clock cycles, echoing the *Whole Earth Catalog*'s 1968 dictum: "We are as gods and might as well get good at it."

Facebook has different values. At its heart, it is a data structure, an enormous social graph of interconnected people, objects, and concepts. Improving that graph, increasing its breadth and density, is the driving ambition of the company's chief executive, Mark Zuckerberg. The better the quality of the database, he believes, the better the proposition for users and advertisers. The network, the graph, is to Facebook not a means to an end but the thing itself.

No other company is like Facebook. It is an advertising-driven business that grows by routing more human social signals through its enormous proprietary network. As people use mobile devices to do more things, the company needs to capture more of smartphone users' attention. Globally, people send 8.6 trillion text messages each year, and not through Facebook. Choosing not to limit itself to an app on smartphones, Facebook has built on Android, grafting onto it a new interface layer it calls Facebook Home.

It is an imperfect graft, and it may not take. One reason is the less-than-happy implementation of Facebook's idea. But the broader problem is that the social-networking company's vision of the relationship between humans and computers is at odds with the Palo Alto tradition, which the world has irreversibly embraced. If there is a conflict between Facebook Home and the Android system on which it is built, it's this: Android knows many small things, and Facebook Home knows only one big thing.

Avatars

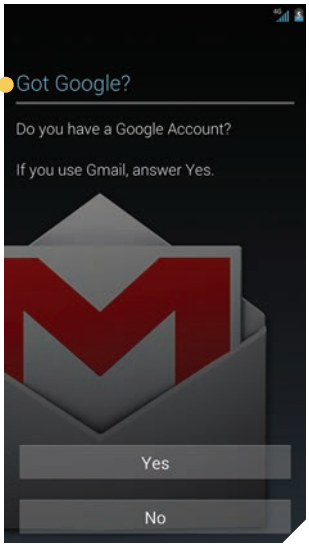
First, the implementation. For two weeks I carried the HTC First, the first smartphone to come with Facebook Home installed, as my primary mobile device. The hardware is the standard marvel of miniaturization—that is, it's wonderful today, but it will be next year's junk. Launching Home on Android was probably a choice of expedience, because Android's standard license permits modification. Facebook is reportedly negotiating with Apple to add the Home interface to iOS, but it's easy to imagine those negotiations going on for some time.

From the moment the phone turns on, one encounters a lack of resolution (of the old-fashioned kind—the phone itself has a high-definition screen). The f-in-a-circle logo on the box promises a Facebook experience, but the first thing the phone demands is your *Google* account information. And from that moment, Facebook Home is a series of compromises.

True to its name, Home overtakes the home screen of the phone, removing the dock of favored icons at the bottom and replacing them with the user's avatar (in my case a photograph of my head). By tapping and holding the avatar, one brings up a few grayish icons; dragging the avatar onto an icon summons, for example, the application home screen. Perhaps Facebook hoped that making people move a tiny representation of themselves would create an intimate connection with the

Illustration by Dan Page

A Series of Compromises

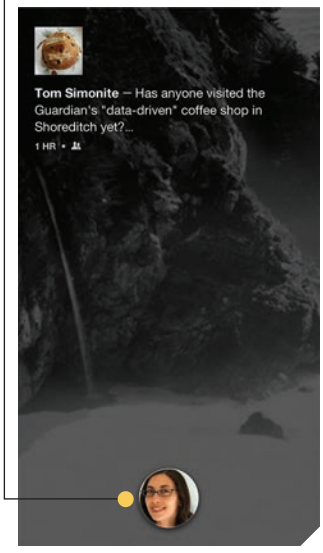


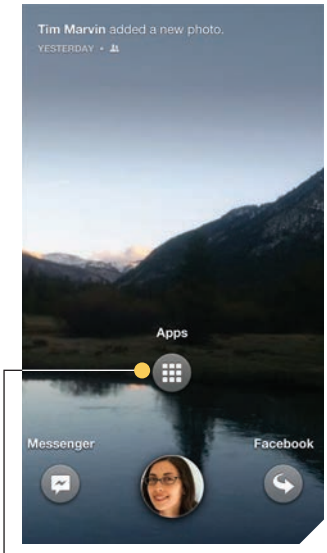
LOGGING IN

The first thing the phone demands is your Google account information.

HOME SCREEN

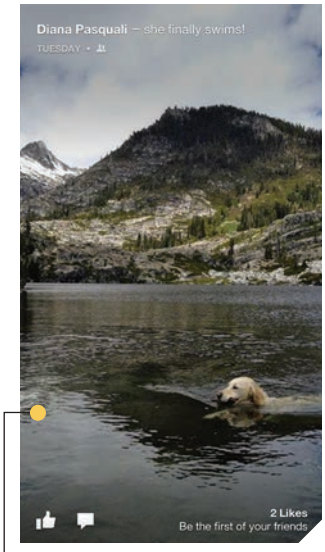
The typical dock of favored icons is gone. It's replaced by the user's avatar.





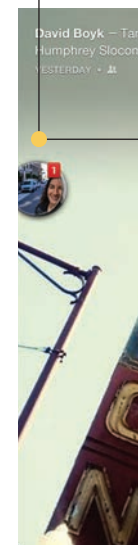
ACCESSING APPS

To open an application, the user taps and holds the avatar and drags it onto the app's icon.



STATUS UPDATES

When the user is not engaged with an app, the home screen displays updates from Facebook friends.



device. But the result is friction: too many steps between my finger and the application (say, Gmail) that I want to open.

When the user is not engaged with an app, the home screen displays images and status updates from Facebook friends. You can quickly swipe from update to update, or the phone will do it for you. The most recent update comes first, so the effect is of moving backward in time. A home screen of updates is clever, because picking up a phone and fiddling with it is something people do dozens of times a day, and Home colonizes those moments with Facebook content. But the selection algorithm is indiscriminate, and the noisiest people come to dominate the home screen; I learned a lot in two weeks about some old high-school friends but very little about the people closest to me. Though some meaningful signal rises above the background noise of chatting acquaintances, the final effect of the home screen is like being at a crowded reunion of half-remembered faces rather than on the eternal holiday promised in Facebook's advertising campaign. Perhaps I am too old to appreciate the party.

To "like" an update, one can click a small icon or tap twice. In general, this is a bad phone for anyone with poor motor control. For me, swiping status updates was likely to pull down Android's native notification drawer. Sometimes I would tap something on the home screen—a name, for example—by accident and find myself linked into Facebook's Android app. It was easy to become lost in a sequence of actions, none of them meaningful.

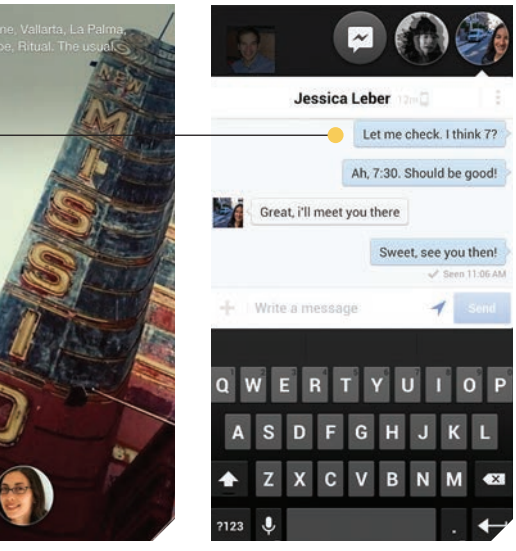
And then there were the "chat heads." When someone sends you a message, small, circular avatars appear with a pop. They indicate conversations *in medias res*; tapping one brings up a chat in progress. They are persistent, although they will disappear when you enter an app with a full-screen mode, such as the Kindle reader. The heads themselves are neat, but they are large enough to occasionally hide elements, even in Facebook's own app. I spent some time looking for a way to post a Facebook status update before I realized that the button I wanted was behind the smiling face of my wife.

A way of being

The real goal of Home is to replace apps with people, making the process of interacting with a smartphone inherently social. The marketplace has so far responded without warmth. The price of the HTC First has dropped from $99 to 99 cents with a contract. And yet given Facebook's size and the scope of its ambitions, and the fact that Home is a small effort in the scheme of things, it's safe to assume that all this is just a shot across the bow. Home-like features, such as the chat heads, have already found their way into Facebook's

CHAT HEADS

Avatars enclosed in circles appear with a pop when a new message comes in. Tapping one brings up a chat in progress.



app, and they will no doubt appear in other phones. The company must own more of the smartphone—not of the market, but of the phone itself—to continue to grow.

Amazon's Kindle Fire is also based on Android. Amazon sells digital access to books, films, and the like, which is to say that Amazon understands its users as consumers of media: they might do other things with their Fires (including checking Facebook), but they are interested in personal interactions with media—interactions that can be sustained for hours or even, in the case of some books, weeks.

But hours spent reading a book are hours lost to Facebook. Smaller pieces of content that encourage immediate reaction do more to bolster and enlarge the social graph. Facebook has created an environment that elevates a few lines of text, the individual photo, people who can be poked, things that can be liked. Dancing, live music, vacations with good phone reception—all these are good for the social graph.

This is the stuff of the home screen in Facebook Home. The chat heads are small and the conversations brisk; I didn't have a chat longer than a few minutes, and a typical sentence might be just a few words. When these chats were done, they faded immediately from my memory, as did most of the things I swiped away on the home screen. The goal of Facebook Home is ambiance, not permanence.

But when we use computers, we're used to creating and consuming things that possess some permanence. Even though smartphone interfaces generally abstract away files and folders, the underlying model of computing has remained unchanged since Kay's time at Xerox PARC: the user opens an application, loads it into memory, and uses software tools to operate on specific blobs of data. Dropbox is one of many services that hold your files in the cloud so that they can be accessed from any phone, tablet, or computer. You may never share what you create or own, or you may share it only years later. People have written and read novels on their smartphones. The joke about the first iPhone was that it was a great little computer but a lousy phone. That didn't stop people from buying it: they understood the value of having a computer in their pocket.

It's funny how rarely people ask what Facebook is for. It's for perpetuating Facebook.

The social network, however, is not a tool but *a way of being*. If you want to leave a note for yourself on Facebook, using the service as a notebook, you must share it with yourself—selecting the "only me" option from a list that also includes "public" and "friends." It's funny how rarely people ask what Facebook is for. We've just come to accept it, this mountain that rose up one day and is never quite out of view. It's not really *for* anything, certainly not for tasks and documents. It's for perpetuating and improving the social graph. It's for Facebook.

Moral vision

Facebook's self-reflexive utility explains why the company finds privacy so tricky. The freedom to read and experience things privately is essential to self-development, the core proposition of the Emersonian ideal to which the Palo Alto tradition is heir. But Facebook's core proposition is that when we collectively build the social graph, everyone benefits. The exact nature of those gains is perplexing; the company's commercials show a lot of young people touching and smiling. *Something* good.

It's not simply the case that Zuckerberg is sneaky in his promotion of sharing and creepy in his ambivalence about privacy. Rather, he is a true believer. Privacy lowers the value of the social graph. If one sincerely believes in the merits of the graph, then one *should* be suspicious of privacy, because privacy is selfish.

The moral vision of the Dynabook posited that people would use technology to manipulate code and data, to create models of the world—as many as they needed in order to understand it. In contrast, Facebook has a single model of the world, unapologetically monolithic: the canonical graph of the relationships between more than a billion human beings. If the company is to grow, it must insert itself between people and their smartphones; there are still simply too many moments spent watching things, or reading things, or making things, that it does not own.

Paul Ford is a writer and computer programmer who lives in Brooklyn. He is writing a book of essays about Web pages.

RACHEL METZ/MIT TECHNOLOGY REVIEW


TCHO

A Chocolate Maker's Big Innovation

In transforming the way cacao farmers supply manufacturers, a San Francisco startup is creating a superb product.

By Corby Kummer

You may have seen little squares of Tcho chocolate in their brightly colored wrappers decorated with futuristic parabolas of gold and silver. They're easily found: Starbucks has sold them; Whole Foods sells them now.

Those usually aren't the stores you visit to track down handcrafted chocolate from bean-to-bar makers, the new wave of chocolate producers that find and blend the rarest and most richly flavored cacao beans. Artisans like Mast Brothers, in Brooklyn, promise that each batch of bars will be different; nothing will be blandly mass-produced. In a video on their website, the lavishly bearded Mast siblings extol the "inconsistency" of their chocolate. Inconsistency generally isn't what gets you orders from Starbucks and Whole Foods.

Tcho chocolates
www.tcho.com

But Tcho makes chocolate as interesting as Mast and other tiny producers. The San Francisco company stakes its reputation not on the exotic-sounding varietal names or confusing cocoa percentages the artisans market but on a set of flavor characteristics: chocolatey, bright, fruity, floral, earthy, and nutty. Tcho's "PureNotes," illustrated as a pie chart on wrappers, is partly a marketing device. But the chart represents something real. It makes you aware of the range of flavors you should be looking for in good chocolate, and of what you may be missing when you bite into the most dully industrial or ostentatiously artisanal versions.

What sets Tcho apart from other chocolate makers is that it doesn't just scout the equator looking for cacao farmers it can admire, hoping they'll grow great beans that might make wonderful chocolate. The company does something new: it provides growers with all the tools they need to have chocolate tastings during harvesting and processing, the crucial period that determines the price a cacao farmer's crop will command. Tcho combines coffee roasters, spice grinders, and modified hair dryers to equip "sample labs"—pilot plants that produce tiny lots of chocolate right where cacao is grown. The company gives cacao farmers customized groupware so that they can share tasting notes and samples with chocolate makers. In this way, the farmers can bring entire harvests up to the standards of Tcho or any other buyer.

This is a huge change. Just as some coffee growers have never drunk coffee made from their beans, some cacao growers in remote areas have never tasted chocolate made with theirs. (Since chocolate is much harder to make than coffee, some may have never tasted chocolate at all.) Teaching them to recognize the flavors in fermented, roasted, and ground cacao beans, and then understand how they can adapt their growing processes, will be Tcho's lasting contribution to chocolate making—even if hair dryers and spice grinders weren't quite the tech the company had in mind when it opened a factory and shop on a historic pier in San Francisco's Embarcadero, in 2007.

Field testing

With cacao, the way a bean is fermented plays as big a role in flavor as *terroir*, that all-important concept in coffee and wine. Fermentation is as important as roasting or even factory production. The process lasts five to seven days, and the temperature and humidity at which it takes place and the frequency with which the beans are turned for aeration determine the flavor profile a roasted and ground bean will ultimately possess. The goal is not only to avoid defects but to develop complex flavors.

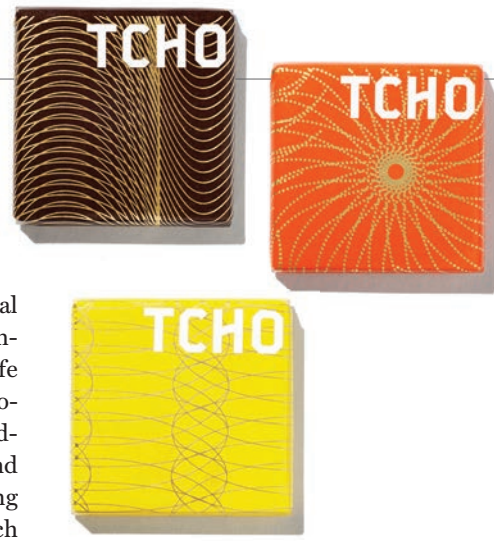
Tcho leaves the roasting to big producers with finely tuned machines. The company receives the cocoa liquor, the paste made from ground roasted beans, in big blocks that it melts, mixes with cocoa fat in various blends, and stirs. Long, slow mixing is part of the chocolate mystique. *Really* long: 24 to 36 hours of slow stirring in a vat that is called a conche for the rounded bottom that allows liquid chocolate to be rolled back onto itself, which incorporates air and smooths the texture.

Conching can iron out harshly acidic notes. But the artistry is in creating a creamy mouthfeel and preserving the acidic notes the chocolate maker does want: the finished chocolate will have balance and zest if the maker can highlight a fruity acidity. Roasting and conching are what bean-to-bar makers brag about, and where Tcho thought it would innovate.

Technology is in Tcho's DNA. Its cofounders were Timothy Childs, who had worked on the space shuttle, and Karl Bittong, who labored in the chocolate industry for 40 years. Its current CEO and president are Louis Rossetto and Jane Metcalfe, the cofounders of *Wired*. In the early days, Tcho introduced a variety of high-tech gimmicks, including an iPhone app that could control the produc-

STYLING BY CATRINE KELTY

Photographs by Adam DeTour



tion process and a video-game-like virtual tour of its production floor using tilt-pan-zoom cameras. Rossetto and Metcalfe embraced a still in-use beta-testing program for new blends of chocolate, sending samples to anyone who signs up and promising to adjust the blend in keeping with the results of online surveys. Such ideas attracted tech-industry investors. But they don't have much to do with the product. Even if the beta samples make customers feel like part of an elite cadre, crowdsourced formulas don't necessarily produce good chocolate.

The sample labs are less flashy than a virtual tour, and they took more time to develop. First, the company had to find a nonprofit partner to help secure government grants, as new-wave coffee roasters often do. Tcho teamed up with Equal Exchange and won a five-year, multimillion-dollar grant from USAID.

They retrofitted off-the-shelf appliances to create makeshift but reliable roasters and conches for cacao farms. Indian spice grinders, generally used for the lentil mash dhal, became conches; cheap blow-dryers kitted out with electronics and heat sensors became heaters for the conches. Twelve hours of steady, low-heat stirring result in a "completely smooth, European-style chocolate eating experience," says Brad Kintzer, the chief chocolate maker, who travels frequently to set up the sample labs. A whole lab, according to John Kehoe, vice president of sourcing and development, can be installed on site for about $10,000. Tcho has installed labs in Peru, Ecuador, and the Dominican Republic; Ghana is next.

Tcho creates blends that are better than those of the international mass producers.

It took years to develop an evaluation scale that farmers could understand and use to home in on the styles Tcho envisioned as its signature blends. But a tasting and tuning system eventually took shape: Tcho installed the labs on site and made sure each site had access to a computer and to groupware called Cropster, where growers entered data on heat, temperature, humidity, pH, and brix level (the degree of sweetness). Growers would ship samples of the cocoa liquor to Tcho, and then Tcho would set up tastings at which two panels, one at the farm and one in San Francisco, compared notes on Cropster in real time.

If all agreed that a fermentation method wasn't yielding good results, the size and placement of the fermenting boxes could be altered. So could the heat and humidity, the time and temperature at which the fermenting cocoa was turned, and the number of days the beans were allowed to ferment.

Without the sample labs, Tcho was in the same position as other chocolate makers: by the time the fermented beans arrived, it was too late to make any changes. The only choices were to place an order or wait till the next harvest. Now, a farmer can make adjustments that will ensure a sale. The sample labs and Cropster are licensed shareware; that means farmers can adjust fermentation to suit the needs of other customers too.

Clean and easy

After its high-flying beginnings, Tcho has settled into being a high-end but large-scale chocolate maker. It creates blends that are better than those of the international mass producers yet not as quirky as Mast Brothers' or those of Taza, an artisan producer in Somerville, Massachusetts, whose stone-ground, gritty blends conform to the earliest, pre-conching methods of making chocolate in Mexico. That kind

Partnering with Equal Exchange, Tcho retrofitted off-the-shelf appliances to equip "sample labs"—pilot plants that produce tiny lots of chocolate where cacao is grown. Now farmers can make adjustments to suit the needs of their customers.

COURTESY OF TCHO

of compromise might keep it alive longer than the bearded-artisan startups. Tcho is careful about not overreaching. It eschews trends. Apart from coffee in its "Mokaccino" bars, it adds nothing to its chocolate. There are no Tcho chili chocolates, and not even Tcho with nuts, just a "Nutty" PureNote.

What Tcho has achieved can best be understood by contrast. The chocolate made by Equal Exchange Organic Ecuador (to pick one new-wave, medium-scale maker) is bland, sour, and monochromatic by comparison with Tcho's "Fruity" variety. The Tcho blossoms on the tongue and opens out to the bright acidity of the best Central American chocolate.

Or consider Mast Brothers' cocoa nibs bar: it also blossoms out, with dark-roasted notes and the satisfying bitter crunch of broken roasted nibs—but then it flattens, and you begin to notice a waxy texture. Tcho's mouthfeel is easy, creamy, and clean, with a sharp snap.

Maybe the most telling contrast can be found in Tcho's blends of "SeriousMilk" chocolate, "Classic," "Creamy," and "Cacao." Now, I don't like milk chocolate (I'm too sophisticated). I was sure that if I could bear any of them, it would be the darker, less-sweet "Cacao." Instead, I fell hard for the caramel, butterscotch, sweet-but-not-too-sweet "Classic," which erased my memories of childhood Hershey bars. Those are the chocolates I took home.

I suspect I'm not alone in loving Tcho. After initial flashy gimmickry, the company has found a quiet way to please many customers. Along the way, it's changing how chocolate is made.

Corby Kummer is an editor at The Atlantic *and the author of* The Joy of Coffee.

Minecraft players build what they will, like this model of Frank Lloyd Wright's Fallingwater.

JACOBMATHEWS/IMGUR.COM

The Secret to a Video-Game Phenomenon

Eschewing grit and realism for creativity and simplicity, Minecraft has heralded a new era in which bedroom programmers can bypass publishers and still see their creations become global hits.

By Simon Parkin

All video-game makers are minor gods. They are, after all, in the business of world creation. The game creator sets down the mountains and arranges the valleys in his or her world. The creator decides upon the sky's hue, the water's viscosity, the pitch of birdsong, and the force of gravity's pull. The creator types "Let there be light" (or the C# equivalent) and there is light. The creator chooses how and when night falls and whether or not there will be a new dawn. The creator conjures how time works (linear, malleable, or something else entirely) and writes the strands of code that form the incumbent creatures' DNA. Then,

Minecraft
Available on PC, Mac, Xbox 360, iOS, Android

when everything is planned out, the creator clicks "RUN" to execute a Big Bang.

Among such gods, Markus Persson, the Swedish creator of Minecraft—a video game that has, in the four years since its initial release, become a 21st-century sensation, played in bedrooms and classrooms around the world—is something of a Zeus. More than 22 million people have paid to immigrate to his world and settle there (nearly three times as many as live in the gigantic multiplayer game World of Warcraft), be it on PC, smartphone, or video-game console. Released without backing from investors or publishers, Minecraft is inspiring a new generation of independent game makers to strike out on their own, and to approach their medium in new ways. Meanwhile, the profits it's generated—$86 million in 2012 alone—rival those of the world's largest entertainment releases.

Such incomparable success is unexpected. Minecraft embodies few of the video-game fashions that were current when it appeared. Coded in Java, a general-purpose programming language that emphasizes speed and lightness over the grand capabilities of more powerful tools, it features pixelated scenery that has nothing in common with the lifelike, polygon-stuffed characters and objects furnishing the blockbuster video games of the day. There is a certain Lego-like charm and blunt handsomeness to the rectangular clouds that throw shadows on the game's pea-green hills and the dumpy sheep that roam them. But in an industry traditionally obsessed with chasing realism and authenticity, its kindergarten aesthetic at first appears anachronistic.

FROM LEFT: HELLZOULZ1/PLANETMINECRAFT.COM; HUTTIFNUTTI/PLANETMINECRAFT.COM; CHARLES MCCORMICK, WESTEROSCRAFT

Minecraft places its player in the game's world with few directives. There are almost no goals.

Moreover, where the creators of big-budget games are now as much movie directors as gods—shepherding their players through scenes and treating their characters like actors, with scripted lines of dialogue and stage directions—Minecraft places its players in the game's world with few directives. There are almost no goals or commandments to guide or moderate behavior, apart from those of the players' own making. So what accounts for the game's success? Its intelligent design reveals a watchmaker's precision, while the elemental freedom it offers its inhabitants taps into some primal, irresistible human urges.

In the beginning you're given your own algorithmically generated world (each new game creates an expanse of blocky geology that nobody, not even Persson, has seen before), and little more than the title functions as a clue to your tasks: to mine and to craft. These twin abilities—destruction and creation—are mapped to the game's two main buttons. Press one and your stumpy arm will flail in front of you with comic speed and repetition, chipping away at whatever object you're looking at, eventually reducing it to a floating cube of material that may be collected and stored in your inventory. The nature of the harvest is dependent on the material you "mined." Chopping a tree will produce a block of wood. Chopping a cliff face will yield a chunk of granite. Hammer the beach and you'll nab a cube of sand.

With these raw materials you are free to build. At first you might experiment with a waist-high wall, laying blocks side by side in a straight line. Now, embold-

ened by your success, you turn it into one of the four walls of a small house, blocking out the light with a flat roof before knocking through the door you neglected to account for in the original design. Meanwhile, the sun has wheeled in the sky, unnoticed by the novice. Night falls and the eerie sounds of scratching monsters arise. At this point Minecraft's ambiance shifts, and you realize that as well as a playpen for the imagination, this is also a world of peril.

Some projects require more effort than others: a sprawling attempt to re-create landmarks from Game of Thrones*, seen in the illustration farthest to the right, represents the kind of large-scale undertaking some players have coördinated. Blocks of unusual colors can be carefully sought out and mined or forged, turning the game into a kind of scavenger hunt.*

You retreat into your creation or, if it remains unfinished, hurriedly hollow out a cave in the side of a mountain in which to quiver and cringe till morning, when the skeletons and zombies dissipate and you're free to return to your construction. The game's rhythm established—build during the day, shelter during the night—you continue with the chaotic implementation of your half-cocked ideas. The hut becomes a shack becomes a lodge becomes a house becomes a mansion becomes a castle. Through a rudimentary tutorial you learn that certain blocks require certain tools, and using a craft bench you begin to fashion simple utensils: a pickax, a shovel, a hoe, a sword. As the range of blocks you've harvested diversifies, the range of domestic features you can build widens, and soon your abode is furnished with candles, paintings, elaborate stairwells, and bay windows.

The pleasure of construction is matched by the thrill of destruction, our play reflecting the very rhythms of life: birth, death, and rebirth. Minecraft understands that for humans, the business of creation is closely linked to the business of survival. The threat of the nighttime monsters brings focus to your industry, while the richness of materials found in the world facilitates the personal touch, encouraging craftsmanship.

Perhaps this would be enough to make Minecraft a million-seller, but what has turned success into sensation is the social aspect of the game. Not only are players encouraged to head out of its confines onto YouTube to share tips or show off their grand designs, but the game also allows for communal construction projects, in which players can visit one another's worlds and collaborate on virtual pyramids, a scale replica of the Taj Mahal, or a fully mapped Westeros, the fictional land from HBO's television

series *Game of Thrones*. The inclusion of giant, hand-built logic gates has enabled some smart players to build functioning computers, scrawled boastfully into the landscape, while other players have opted to simply journey to the center of the earth.

Here is a game that offers an accelerated form of existence—of dominion but also of stewardship.

Last year this indie game overtook Activision's blockbuster war game Call of Duty as the most played title on Microsoft's Xbox Live. The implications of this feat are wide ranging. For one, it shows that a creation game rather than a shooting game can rise to dominance. It also confirms that contrary to big-publisher wisdom, players are more interested in expressive and interesting interactions than simple graphical prowess, whose charms are fleeting.

For a generation of young game makers, empowered by more accessible tools and ubiquitous platforms including mobile devices, the game provides commercial inspiration. In a medium that sprang from student endeavor and bedroom programming only to see the power inevitably shift to companies and, eventually, megacorporations, it's again possible for the bedroom programmer to become a multimillionaire. Since Minecraft's rise to prominence, hundreds of young players have been inspired to make their own games, either through structured learning in schools or by using free or cheap tools such as GameMaker on their own. Thanks to Minecraft's example and the ease of self-publishing through channels such as the Apple App store, Google's Play Store, and Steam, independent video-game studios are enjoying an unprecedented burst of success.

Fitting then, perhaps, that Persson's purpose with the game is somewhat evangelical, although it isn't revealed until the closing credits. While Minecraft's loose, player-defined goals are its strongest draw, there is an endgame for those who feel the need to beat a video game rather than simply enjoy one. If at this stage a giant dragon is discovered and felled, that will conclude the story line. The reward for defeating the dragon is a poem, written by the Irish novelist Julian Gough, that describes Minecraft as a dream. It reads:

> This player dreamed of sunlight and trees. Of fire and water. It dreamed it created. And it dreamed it destroyed. It dreamed it hunted, and was hunted. It dreamed of shelter ... And the player started to breathe faster and deeper and realised it was alive, it was alive, those thousand deaths had not been real, the player was alive ... And the game was over and the player woke up from the dream. And the player began a new dream. And the player dreamed again, dreamed better.

Minecraft's mainstream appeal may not lie in the poetry tucked away in an endgame few will see, but it is to be found in this poetry's sentiment. Here is a game that enables humans to experience an accelerated form of existence—of dominion but also of stewardship. It makes clear the ancient ties between creativity and survival, and the wonder of collaboration, coöperation, and community, both in its world and in the reality on the other side of the screen. This is a recipe that demonstrates how video-game design, in the right hands, can be elevated to an art form every bit as strange and wonderful as any other, revealing deep truths about the human condition.

Simon Parkin is the author of The Illustrated History of Video Games *(Anness Publishing).*

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Demo

1

Plastic from Grass

Engineers seek a cheaper biodegradable polymer.

By David Talbot
Photographs by Ken Richardson

Nearly all the plastics sold today come from petroleum and aren't biodegradable. But researchers at Metabolix in Cambridge, Massachusetts, are genetically engineering switchgrass to produce a biodegradable polymer that can be extracted directly from the plant.

That could transform the economics of making biodegradable polymers. Metabolix already sells such a polymer, but it's produced by bacteria that feed

1 Oliver Peoples cofounded Metabolix with biologist Anthony Sinskey.

2 Plastics production begins with switchgrass seeds.

3 In a petri dish, cell cultures derived from the switchgrass seeds are exposed to a solution containing engineered bacteria that transfer new genes into the cells. Some genes, borrowed from soil bacteria, alter the grass's metabolic system to produce a polymer known as PHB.

4 The cell cultures are placed on a medium that includes an herbicide; cells that failed to incorporate the new genes are killed off. Modified cells include a gene that allows them to tolerate the herbicide.

5 With the help of a growth medium, the surviving cells develop into plants whose modified genes enable them to produce plastic.

6 After several weeks, the plants are transferred into peat pellets. Later, they're transplanted in a greenhouse.

7 Months later, the cut and dried grass is ready for industrial processes to extract the PHB.


2


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8 Peat balls in Metabolix's greenhouse are kept in plastic bags to maintain humidity. Young plants are tested to ensure that they're producing PHB. In the background are maturing grasses.

9 In one promising method to recover and use the PHB, chopped switchgrass is first placed in a stainless-steel chamber.

10 The chamber (right in photo) is next heated to 300 °C, breaking down the PHB into a chemical called crotonic acid.

11 The crotonic acid gas is captured and cooled in a condensation process adjacent to the heating chamber.

on plant sugars in expensive fermenters. A plant-based process, which could use crops grown on marginal lands, would require less equipment.

Metabolix estimates that it could ultimately sell its plant-based polymers at less than half today's prices. Whereas today's end products are niche items like biodegradable plastic shopping bags, more widely used types of products and packaging could then become economical.

The plants-to-plastics vision has gripped Metabolix's chief scientific officer, Oliver Peoples, a former MIT research scientist, for more than 20 years since he and colleague Anthony Sinskey, an MIT biology professor, discovered metabolic genes that allow bacteria found in soil to naturally produce a polymer known as PHA. But after they founded Metabolix, it took a decade to optimize metabolic systems in the bacteria to produce useful amounts of PHA. Doing so in plants is even more difficult. "It's much more complex and time-consuming to engineer a complex and slow-growing species like switchgrass versus a very simple bacterium," Peoples says.

Now, Metabolix plant scientists are working anew on inserting those genes, plus others that regulate growth, into plants including switchgrass, camelina, and sugarcane. In switchgrass, they're coaxing the plant to produce and store

12 The resulting crotonic acid, shown here, is a key feedstock for plastics and chemical products.

13 The remaining scorched biomass is removed from the chamber. It could be burned along with coal in existing power plants.

14 – 17 A different and more capital-intensive process could directly extract the PHB for use in making plastic products. This method starts by putting the chopped grass in a solvent, which frees the PHB (14). The resulting liquid is reserved (15), and another solvent is poured in (16). This allows the PHB to precipitate out of the solution (17).

in its tissues a specific type of PHA, known as PHB, that can be used to make injection-molded products such as electronics housings. The company is also working on chemical production steps, including extraction of the PHB using solvents, and a thermal method of converting the PHB into a chemical called crotonic acid, which can be used as a feedstock for polymers. After the PHB is extracted or the crotonic acid produced, remnants of the grass could be burned as a biomass energy source that produces lower net carbon emissions than fossil fuels.

Metabolix calculates that the grass must produce 10 percent of its weight as PHB to be economically competitive with other sources of biodegradable plastics. The company has already nearly doubled the PHB content in switchgrass, from 1.2 percent in 2008 to 2.3 percent last year, including 7 percent in the leaves. The process would still produce some carbon emissions: growing and harvesting plants requires fossil-fuel-based fertilizers and fossil-fuel-powered machines. But Peoples predicts it would be cleaner overall than producing plastic from fossil fuels, though a full analysis has yet to be done. For now, he's eager to finally realize his plants-to-plastics vision. "This is a testament to sheer bloody single-mindedness," he says.

75 Years Ago

Untapped Potential

A 1938 article anticipated the opportunities—and challenges—of harnessing the sun's energy.

The enormous potential power in solar energy is revealed by measurements which show that solar heat reaches the earth in the Temperate Zone at the average rate of about 4,000,000 calories per square yard per day. During the three months of greatest sunshine, an acre of land receives directly from the sun an amount of heat equivalent to burning approximately 250 tons of high-grade coal. This measurement indicates that unobstructed solar radiation, transformed completely into useful energy, would produce approximately one horsepower per square yard.

This energy determines our climates, causes winds, ocean currents, and rainfall, and produces photochemical reactions whereby a portion of the energy is stored in plants. Thus, solar energy is the ultimate source of our fuels—wood, coal, oil, and gas—as well as of power derived from wind or falling water. However, the stores of fuel energy in coal, oil, and gas, while great, are not inexhaustible. It is therefore of ultimate importance to investigate and develop alternative sources of heating and power.

Because of the enormous amount of solar energy freely available, the practical problem is not to find means of using it with a high percentage of efficiency but rather to find methods that will be cheap enough to make solar energy economically useful.

There have been many attempts in which mirrors were used to concentrate sunshine as a source of energy for heat engines but, while some of them have been technically successful, they were economically unsound. The problem of economically collecting the sun's heat is a baffling one.

Research on electrical apparatus for utilizing solar energy suggests three approaches. These are vacuum or gas-filled photoelectric cells, thermopiles, and boundary-layer apparatus, such as the copper–copper oxide cell. None of these have been successfully adapted to convert sun energy for power purposes. Although all are notoriously inefficient, one cannot assume that further knowledge and its application may not entirely change the situation. If it should, the possibilities are enormous.

It is evident today, however, that much more information is needed before specific applications can be successfully planned. On the other hand, the ignorance is so vast at present that there remains the possibility that developments in this direction may supersede many other means of power conversion and provide an inexhaustible source of cheap power."

Excerpted from "Converting Sunlight into Power," from the June 1938 issue of Technology Review.

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